MACKENZIE BASIN IMPACT STUDY (MBIS)

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Final Report

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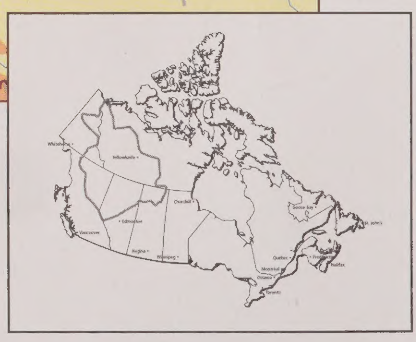

Eric Leinberger, *University of British Columbia*

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1

Final Report

Edited by
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Foreword

It is with great pleasure that I provide these words to the introduction to the final report of the Mackenzie Basin Impact Study. The need for this research effort was first perceived during the late 1980s, as Canada began encountering changes in climate and weather patterns which exceeded our experience. For the first time, Canadians began asking themselves if these events were forerunners to the kinds of extreme events which, because of mankind's influence upon the chemical nature of the atmosphere, might be anticipated more frequently in future. How would these changes in climate and weather impact on our society, our water supply, food production, forests, wildlife, our communities and so forth?

The Mackenzie Basin Impact Study was one of the first attempts to investigate the integrated impacts of global atmospheric change at the regional level. The region chosen included all the land drained by the Mackenzie River and its tributaries - 1.8 million square kilometers. Although Environment Canada, under the leadership of Dr. Stewart Cohen, was the lead agency involved in the project, many partnerships were developed with a wide range of stakeholders. The Mackenzie project was both multidisciplinary and interdisciplinary, and promoted the active involvement of scientists, policymakers, decision-makers, and, perhaps most importantly, community members - those people living in the north who will be most directly affected by climate change. Such involvement set the stage for stakeholders to better prepare for and respond to changing climatic conditions and their impacts.

One of the first workshops of the project focused on identifying the most important questions needing to be answered. The final workshop, held in May of 1996, focused on whether or not the project, in seeking answers to those questions, made a difference to decision-making in the north. The stage was set for continued involvement by local native groups, community members and leaders, scientific and educational organizations and federal and territorial governments. The study is now concluded, but it has spawned new levels of involvement focused on such issues as interjurisdictional water management, sustainability of ecosystems, economic development, the maintenance of infrastructure, and the sustainability of native lifestyles.

May I take this opportunity to congratulate all sponsors and participants in this highly successful experiment in integrated impact assessment. By learning to adapt today to changing conditions, you have helped to prepare a better tomorrow for future generations of Northern Canadians.

David Grimes

Director General
Policy, Program and International Affairs
Atmospheric Environment Service
Environment Canada

Acknowledgements

The Mackenzie Basin Impact Study has been made possible by financial support from the Government of Canada (Green Plan) and Environment Canada. Other direct financial support was provided by Indian and Northern Affairs Canada, Government of the Northwest Territories Department of Renewable Resources, Alberta Environmental Protection, Aurora Institute (formerly Science Institute of the Northwest Territories), Canadian Global Change Program of the Royal Society of Canada, Canadian Polar Commission and Esso Resources Limited.

Additional support for component studies was provided by National Science and Engineering Research Council, Environmental Innovation Program, Emergency Preparedness Canada and Tourism Canada. Data and other in-kind assistance were contributed by Agriculture Canada, Fisheries and Oceans Canada, Natural Resources Canada, British Columbia Hydro, British Columbia Ministry of Forests, Government of the Northwest Territories Department of Energy, Mines & Petroleum Resources, Aurora College (formerly Arctic College), University of Victoria and University of British Columbia.

Community support in the Northwest Territories was provided by the following: Dene Nation, Gwich'in Tribal Council (Gwich'in Interim Land Use Planning Board), Inuvialuit Game Council, Metis Association of the Northwest Territories, and the communities of Aklavik, Fort Liard, Lutsel k'e (Snowdrift) and Pedzeh Ki (Wrigley). This support made it possible for researchers to conduct studies within aboriginal communities.

Opinions expressed in this report are those of the authors and do not necessarily reflect the views of Environment Canada. The MBIS has been a broad collaborative research effort involving scientists and stakeholders from governments, universities and the private sector. Many of them contributed writings and comments to this report. The MBIS became a reality because of their participation, and I hope this kind of shared learning experience can continue as the region enters the next century.

Special thanks to Barrie Maxwell, Ranjit Soniassy, Terry Zdan, Neil Parker, Ross Herrington and Steve Matthews for their important contributions to the MBIS Working Committee and at other activities throughout the 6 years of MBIS.

Thanks also to various MBIS advisors, Working Committee members, Environment Canada colleagues and others for their guidance, especially during the challenging early years of the program, including: Tom Agnew, Brad Bass, Joe Benoit, Ross Benton, Richard Binder, Mike Brklacich, Jim Bruce, Gregg Brunskill, William Carpenter, Bill Chin, Randy Cleveland, Henry Cole, Ron Cruikshank, Kirk Dawson, Paul Egginton, Helmut Epp, Alan Fehr, Ruthann Gal, Tim Goos, Richard Gordon, Nelson Green, David Grimes, Bruce Hanbidge, Ray Hesslein, Martha Johnson, Bijou Kartha, David Krutko, Rick Lawford, Hao Le, Frank LeMouel, Al Malinauskas, Phil Marsh, Barney Masuzumi, Cara McCue, Robert McLeod, Scott Meis, Carole Mills, Michael Moir, Fred Roots, David Sherstone, Walter Skinner, Barry Smit, Jamie Smith, Chris Tucker, Valoree Walker, Gary White, Yongyuan Yin and Steve Zoltai.

Thanks also to the Atmospheric Environment Service of Environment Canada, North York (Downsview) Ontario, and in particular, the Environmental Adaptation Research Group including past director Ian Burton and current director Roger Street for their support. Since September 1995, I have been co-located with the Sustainable Development Research Institute, University of British Columbia. My thanks to John Robinson and his staff for providing a stimulating working environment.

The MBIS Final Report was produced with the very able editorial assistance of Derrick Pohl and Laurel Wickberg, University of British Columbia, and the staff at BTT Communications, Toronto. The colour map of the Mackenzie Basin was produced by Eric Leinberger. My thanks to Indra Fung Fook and Christine Massey for administrative support, Jens Haeusser for computer support, and Wendy Avis for assistance with preparing Appendices 2, 3 and 6.

This exercise required a substantial commitment of time, which meant that my family had to put up with a lot of late nights, extended absences, and lessons in Northern geography. I want to thank my wife, Nanci, for her patience, understanding, and assistance in numerous small (and not so small) tasks that made it possible for me to complete my role in this undertaking.

Stewart J. Cohen
5 February 1997

Executive Summary

Stewart J. Cohen
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with contributions from:

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1. Introduction and Objectives

This is the Final Report of the Mackenzie Basin Impact Study (MBIS), a six-year collaborative research effort supported by the Government of Canada's Green Plan and other sponsors. The objective of MBIS has been to assess the potential impacts of climate change scenarios on the Mackenzie Basin region, its lands, waters, and the communities that depend on them. The study was designed as an integrated assessment with stakeholder participation.

The Intergovernmental Panel on Climate Change, established by the United Nations, has concluded that increased concentrations of carbon dioxide, methane and other "greenhouse" gases will lead to a warming of the world's climate. Already, there are signs of climate warming in the Mackenzie Basin in Northern Canada. The Mackenzie Basin, which includes parts of the Yukon and Northwest Territories as well as northern British Columbia, Alberta and Saskatchewan, has experienced a warming trend of 1.5°C this century. Scenarios of climate change, based on experimental results from General Circulation Models (GCM) of the atmosphere, suggest that this region could warm up by 4°C to 5°C between the 1951-1980 period and the middle of the 21st century.

What if the world becomes warmer? What would the effects of warming be? Would it make a difference to our future, and those of our children?

These questions formed the basis of many of the discussions during the MBIS. The "what if" question provided the scenario of climate change impacts, and the "so what" response of stakeholders indicated their views as to the significance of this scenario to them. Questions about response, i.e. "what should be done" were raised, and there were different views ranging from reactive adaptation to proactive emission reductions. This is a complex problem, without a simple solution, and it is linked to the challenge of sustainability of ecosystems and communities in this region, and elsewhere.

The challenge for MBIS has been to describe possible futures, accounting for scientific uncertainties, as well as the economic, technological and institutional changes that are bound to occur over the long term. Despite the uncertainties, more than 150 countries have ratified an international agreement, the United Nations Framework Convention on Climate Change (UNFCCC). This agreement calls on the Parties to take steps to avoid "dangerous anthropogenic interference" with the atmosphere. What could happen that might be considered dangerous, and how could regions and countries prepare for or avoid these changes?

Here is our collective attempt to address these questions in a region of northwest Canada, within the watershed of the Mackenzie River and its tributaries. MBIS participants included scientists and stakeholders from governments, academia, aboriginal organizations and the private sector. Information has been shared across disciplines and cultures, and hopefully, this sharing will continue long after the completion of this report.

2. What is the Short Answer?

There are many unanswered questions, and many new questions related to potential implications for the region , so after six years of research and discussion, is there a "bottom line?" There are four main points:

1. Most of the regional effects of climate warming scenarios would be negative, including landslides from permafrost thaw, reductions in water levels, increases in forest fires and reductions in forest yield. These impacts appear to offset any potential benefits from a longer growing season. Some of these changes have already been observed during the recent 35-year warming trend.

2. Most participating stakeholders have said that in their view, the region can adapt if these changes occur at a slow pace, but if warming occurs quickly, it would be considerably more difficult. If vegetation and wildlife patterns become modified by climate change, traditional Aboriginal lifestyles could be at risk. Long term climate change impacts on communities, however, will also be determined by many other factors, including lifestyle choices made by the region's inhabitants. We do not know what role climate change could play in the future of the "two economies" of the region.

3. The region's greenhouse gas emissions, by themselves, would not be the cause of regional impacts from a warmer global climate, so regional emission reductions would not be enough to prevent these impacts. Intervention of regional stakeholders at national and international levels may be needed so that others become aware of the consequences to the Mackenzie Basin if the UNFCCC fails to slow the impending changes in global climate.

4. Regional effects of global climate change are more than the sum of changes to vegetation, crops, water resources and permafrost. Governments, industries and communities will respond to the combined effects of climate change within the context of other concerns, including economic and institutional changes associated with the globalization of the economy, ongoing aboriginal land claims and the upcoming partitioning of the Northwest Territories into two separate entities. Computer-based integrated assessment models can provide useful insights, but they are limited in their abilities to describe how people and regions relate to climate change and other stresses. Such models must be complemented by a partnership of stakeholders and scientists, in which visions are shared and respected, and information is freely exchanged.

3. Contents of this Report

The MBIS Final Report contains the proceedings of the MBIS Final Workshop, held May 5-8, 1996, in Yellowknife. More than 100 people attended, including researchers and stakeholders from the study area and other parts of Canada as well as scientists from the United States, Europe and Australia.

This report includes texts of opening statements by senior managers of government departments, reports from round table discussions involving regional stakeholders, summaries of climate impact assessments on a wide range of issues, and contributions from studies conducted in other countries. Appendices include reprints of summaries from MBIS Interim Reports #1 and #2, prepared statements by some of the round table panellists, and a list of contract reports.

4. Acknowledgments

MBIS provided full or partial funding for 19 projects during 1991-1996. Another 11 research activities were contributed in-kind to MBIS through Environment Canada, BC Hydro and the University of Victoria. Various data sets were provided by federal, provincial and territorial government agencies. Total research expenditures were $770,000 (see **Table 1**), with an additional $180,000 provided for publications, travel support and other administrative work.

The Government of Canada's Green Plan was the principal sponsor of MBIS activities, providing $700,000. Environment Canada, Indian and Northern Affairs Canada, Tourism Canada and Esso Resources Ltd. also provided direct funding to MBIS for research and other activities. Many investigators obtained additional financial and in-kind support from other sources, such as the National Science and Engineering Research Council, which are not included in the above totals. In-kind contributions of data and research were probably of equal value to directly sponsored activities.

MBIS was directed by a Working Committee consisting of representatives from federal, provincial and territorial government agencies, aboriginal organizations and the private sector (see **Table 2**). The Working Committee reviewed and ranked research proposals for funding support, and provided advice on matters related to research and consultation. Most of the Committee's work took place during 1990-1994.

The MBIS Final Workshop was co-sponsored by Environment Canada, the Canadian Global Change Program of the Royal Society of Canada, Indian and Northern Affairs Canada, Alberta Environmental Protection, Northwest Territories Renewable Resources, Canadian Polar Commission, Aurora College (formerly Arctic College) and Aurora Research Institute (formerly the Science Institute of the Northwest Territories).

5. Highlights from Interim Reports #1 and #2

MBIS Interim Report #1 (1993) outlined the research framework for MBIS, and provided background information on the region, including water resources, sea ice and ecosystems. Scenarios of climate, population and economic

Table 1. MBIS Participants and Contributors

Lead Investigator/Agency	Topic	Duration	MBIS Support ($ 000)	Other In-Kind & Financial Support
Aharonian (U. of Victoria)	Climate-society interactions, Aklavik	1992-94	0	U. of Victoria, Aklavik
Anderson (McMaster)	Petroleum production	1993-96	42	
Andres (Alberta Res. Council[1])	Peace River ice	1991-94	50	Alberta Research Council
Bayley (U. Alberta)	Peatlands	1991-96	84	NSERC[2], Env. Canada, Esso Ltd.
Benton (Pacific Forestry Centre[3])	Forestry: growth and yield, fire, pests.	1992-96	50	B.C. Ministry of Forests, NSERC, NWT Fire Centre, Alberta Forest Service, Nat. Res. Canada
Bielawski (Arctic Inst. of North America)	Traditional knowledge, Lutsel k'e (pre-proposal)	1992-94	22	Lutsel k'e
Bone (U. of Saskatchewan)	a) Settlements, b) Non-renewable resources	1993-96	38	
Brklacich (Carleton)	Agriculture	1992-96	81	Agriculture Canada
Chin (BC Hydro)	Williston Lake runoff	1992-94	0	BC Hydro
Cohen (AES,[4] UBC)	MBIS Framework	1989-96	0	Env. Canada, UBC
Felton (Env. Canada)	Water management	1993-94	0	Env. Canada
Geological Survey of Canada[3]	Permafrost	1991-96	65	Nat. Res. Canada
Gong (U. Calgary[5])	Remote sensing, land	1992-94	20	
Gratto-Trevor (CWS[4])	Mackenzie Delta shorebirds	1992-95	30	Env. Canada
Huang (BCRI[6])	Multi-objective model	1994-96	0	Env. Canada
Kerr (Env. Canada)	Water levels and flows	1993-96	0	Env. Canada, GEWEX[7]
Latour (CWS[4] & NWT Renew. Resources)	Wildlife response to burns	1991-94	28	NWT Renewable Resources
Lonergan (U. Victoria)	Resource accounting, socio-economic scenarios	1991-95	87	U. Victoria, Esso Ltd.
Lonergan (U. Victoria)	Two economies, Wrigley	1994-96	35	Env. Innovation Program, Pedzeh Ki
Maarouf (AES[4])	Geese	1993-96	0	AES[4] & CWS[4]
Majorowicz[9]	Ground temperatures	1995-96	0	Env. Canada
Melville (Sask. Research Council)	Thermal habitat for freshwater fish	1992-95	40	Sask. Research Council
Newton (U. of Toronto)	Community response to floods	1992-94	08	Emerg. Prep. Canada, Aklavik, Fort Liard
Rothman (AES[4] UBC)	Forest economics	1995-96	0	Env. Canada, UBC
Smith (AES[4])	Climate change scenarios	1991-93	0	Env. Canada
Soulis (U. Waterloo)	Basin runoff	1992-94	30	GEWEX[7]
Wall (U. Waterloo)	Tourism	1991-95	25	Tourism Canada
Wein (U. Alberta)	Veg. response to fire	1991-94	10	NSERC[2]
Welch (DFO[8])	Fisheries data base	1991-93	24	U. Manitoba, DFO[8]
Yin (AES[4] & UBC)	Land assessment	1992-96	0	Env. Canada, UBC
6-YEAR TOTAL			769	

__Notes:__ 1=now at Trillium Engineering, Edmonton. 2=Natural Science & Engineering Research Council. 3=Natural Resources Canada. 4=Atmospheric Env. Service (AES) or Canadian Wildlife Service (CWS), Env. Canada. 5=now at U. California-Berkeley. 6= BC Research Institute, now at U. Regina. 7=Global Energy & Water Cycle Experiment. 8=Dept. of Fisheries & Oceans. 9=Northern Geothermal, Edmonton.

Table 2. MBIS Interagency Working Committee

FEDERAL	PROV./TERR.	PRIVATE SECTOR	ABORIGINAL
Agriculture Environment Fisheries & Oceans Indian & Northern Affairs National Defence Natural Resources (former Energy, Mines & Resources, and Forestry) Tourism	Alberta Env. Protection Alberta Research Council British Columbia Hydro NWT Energy, Mines & Petroleum Resources NWT Renewable Resources Yukon Territory Renewable Resources	Esso Resources Ltd.	Dene Nation Gwich'in Tribal Council Indian Assoc. of Alberta Inuvialuit Game Council Metis Association of NWT

Source: Modified from Cohen (1993). NWT = Northwest Territories.

changes were developed, indicating that the study would assume three GCM-based warming scenarios of up to 5°C over an 85-year period ending in 2050. A fourth scenario, based on an analogue of historic warm periods and paleoecological data, suggested a warming of about 3°C. Population and economic changes, without climate change, could encompass four scenarios including high growth, moderate growth, minor decline and substantial decline.

MBIS Interim Report #2 (1994) included 34 papers, plus additional papers contributed from other research programs as part of the biennial Northern Climate Meeting. These were generally reports of work in progress, but some results were reported. Of particular interest were studies on runoff by **Soulis et al. (U. Waterloo)**, and by **Chin and Assaf (BC Hydro)**. For the whole basin, **Soulis et al.** showed that mean annual runoff would decrease by up to 7% for two of the GCM-based scenarios. **Chin and Assaf** showed an increase of 6% for the Williston subbasin in northeast British Columbia, while **Soulis et al.** calculated a small reduction. **Andres (Trillium Engineering)** estimated that the ice season on the Peace River would be shorter by more than one month, and that ice would not progress as far upstream as it does now.

6. What are the Big Issues?

At a 1992 workshop with senior representatives of the Alberta, NWT and Canadian governments, MBIS was advised to direct its efforts towards addressing the following themes:

a) interjurisdictional water management

b) sustainability of ecosystems

c) economic development

d) maintenance of infrastructure, and

e) sustainability of Aboriginal lifestyles.

The 1996 MBIS Final Workshop included scientists and stakeholder participation in round table discussions on climate change impacts and responses, as they would relate to these themes. Some scientists and stakeholders had also participated in other studies taking place concurrently in the region, including the Northern River Basins Study, Peace Athabasca Delta Technical Studies, and Global Energy and Water Cycle Experiment (GEWEX). Experience with these other research programs provided valuable benefits to the discussions on MBIS results.

7. Results from MBIS and Contributed Research

If the region's climate continues to warm, water and land resources would be affected. Some of the scenario results represent a continuation of impacts observed during the current warming trend. However, the rate of change in the scenarios may be quite different, and this is an issue which has been difficult to resolve.

Water

Using input from **Soulis et al.**, other studies from the GEWEX program, and a routing model of the lower Mackenzie, **Kerr (Environment Canada)** developed a scenario of changes in levels and flows for Great Slave and Great Bear Lakes and the Mackenzie River. Results showed that levels and flows would be reduced during fall and winter months. Annual minimum levels would be lower than the extreme low levels observed in 1994/95. This would occur because increased evaporation would more than offset increases in precipitation.

Land

Aylsworth and Duk-Rodkin (Natural Resources Canada) provided an inventory of 3400 landslides for the Mackenzie Valley and Beaufort Sea coastal region. Many of these occurred in areas with ice rich sedimentary rock. Some were triggered by heavy rainfall and forest fires. Along the Beaufort Sea coast, storm surges from the Beaufort Sea has led to coastal recession of as much as several meters per year, as ice rich sediments become exposed and melt during the summer. Using a ground temperature model with a scenario of air temperature warming as input, **Dyke et al. (Natural Resources Canada)** showed that in the discontinuous zone, permafrost would become thinner, and disappear in some areas along the southern margin (e.g. Fort Simpson, NWT). In the continuous zone, the active layer would enlarge by only a small amount. This model, however, did not include indirect impacts through changes in fire frequency, extreme rainfall or storm surges. Farther south in Alberta, **Majorowicz and Skinner (Northern Geothermal and Environment Canada)** have documented that ground surface temperatures have risen faster than air temperatures in much of the province.

Vegetation changes could occur through longer growing seasons and changes in fire. **Hartley and Marshall (Hartley Forest Consultants and University of British Columbia)** developed the Mackenzie Basin Forest Productivity Model for areas of commercial timber (northern British Columbia and Alberta, southeast Yukon) and applied it to a scenario of climate warming, including a fire scenario developed by **Kadonaga (University of Victoria)**. The fire scenario was based on computations of the Fire Weather Index for scenarios of climate warming. In each scenario, the Fire Weather Index increased, indicating that without changes in fire management, fire frequency and severity would increase. The average annual burned area would double. The forest model showed that the direct impacts of a warmer climate would be an increase in mortality for softwoods (i.e. a larger percentage of trees would die each year), while growth would improve for hardwoods. Once the fire scenario was added, however, average tree age would decrease, so yield from all stands of commercial timber, softwoods and hardwoods, would decline by 50%. Additional stress on forests would come from expansion of the range of the white pine weevil and other pests **(Sieben et al., University of British Columbia)**.

Another way that warming might affect vegetation is through changing water levels and water tables. **Nicholson et al. (University of Alberta and Connecticut State University)** developed a peatland growth model, with a classification of 7 types based on observed characteristics, including air temperature and height of vegetation above the water line. If none of these applied for a particular site, this site would be classified as absent of peatlands. When applied to scenarios of climate warming, the "absent" category expanded to include all sites south of 60 N. In this area, the water table would decline by 10 to 50 centimetres. Farther north, however, there would be an increase in peatland sites from Norman Wells to the Beaufort Sea coast, with water tables increasing by 10 to 30 centimetre in some areas. The drying of the south parallels the scenario of fire increase and water level reductions described by other MBIS studies using the same scenarios but very different analytical techniques.

Wildlife

Changes in vegetation and water, as well as climate, would affect wildlife at various stages of their life cycles, including migration and reproduction. Relationships between animals and the landscape are complex, and for many species, climate change impacts have been difficult to project. **Melville (Saskatchewan Research Council)** reported that lake temperatures would increase in response to climate warming, but impacts on freshwater fish habitat could not be determined from available information. Cold water species might experience increased risk, but questions remain about their potential to adapt. Furbearers (e.g. lynx, marten) might change their locations in response to increased fire, but **Latour and Maclean (NWT Renewable Resources and Environment Canada)** have also shown that some species return to burned areas within a couple of years. Changes in water levels were not addressed, and there have been observations from the Peace Athabasca delta suggesting that lower water levels have led to a reduction in the muskrat population (see Section 8e).

Impacts on caribou appear to be more severe. Using a model developed originally for the Porcupine Caribou Herd, **Brotton et al. (University of Waterloo)** suggested that heavier snow cover and increased insect harassment from warmer summer temperatures would lead to reductions in caribou weight within the Bathurst Herd.

Studies on birds were also hampered by the complexity of their lifecycles, particularly the varying landscapes along their lengthy migration routes to and from their winter habitats. These routes are outside the MBIS region, so the studies could only assess impacts on summer habitat. **Gratto Trevor (Environment Canada)** reported that shorebirds found in the Mackenzie Delta would not expe-

rience much change in summer habitat conditions. **Maarouf and Boyd (Environment Canada)** suggested that geese would benefit from the warmer summer, but fire and landslides could damage habitat.

The above studies provide a western science based picture of mixed responses by wildlife to changing environmental conditions. Traditional knowledge could add to this picture. MBIS attempted to do a case study of Lutsel k'e and some information was provided by **Bielawski (Arctic Institute of North America, from MBIS Interim Report #2)**. Unfortunately, full support for this activity could not be obtained. There is an important collaborative research opportunity here, in which western science and traditional knowledge could become partners in exploring potential effects of climate warming on wildlife. This was discussed at length by the Round Tables (see Section 8).

Economic Activities

Reduced forest yield would increase risks for commercial forestry in northern Alberta and British Columbia **(Rothman and Herbert, Environment Canada and University of British Columbia)**. Agriculture could benefit from the longer growing season, but expanded irrigation would be required in order to make a commercial operation viable **(Brklacich, Carleton University)**. Two case studies of tourism impacts show mixed results, with water based recreation in Nahanni National Park experiencing minor changes, but losses in the Bathurst caribou herd would hurt sport hunting. **(Brotton et al., University of Waterloo)**. Offshore energy development in the Beaufort Sea could benefit from the longer summer, but the prospect of increased coastal erosion and storm surges would lead to higher costs and environmental risks **(Anderson and DiFrancesco, McMaster University)**.

Communities

Impacts on communities will depend on economic, technological, political and social changes, all of which will influence community responses to climate. Current responses to flooding, for example, vary depending on previous community experience, availability of all season roads, and arrangements with other levels of government **(Newton, Newton Associates)**. In a climate change scenario, floods would still occur but there would be problems associated with lower minimum water levels **(Kerr)**. Some communities would also experience increased risk from landslides and ground subsidence from permafrost thaw **(Bone et al., University of Saskatchewan)**. Resource based communities and native settlements may have different challenges to face because of different levels of infrastructure, but this will not be just a question of engineering. In the long term, land claims and various external economic pressures will influence how communities' wage and non-wage economies evolve **(Lonergan et al., University of Victoria)**. Changes in forestry, agriculture, water and wildlife resources may lead to new wage opportunities in farming, but also new risks in wildlife harvesting, forest harvesting, non-renewable resource extraction and transportation. How will this affect the two economies of northwest Canada? MBIS has only just scratched the surface of this complex but important issue.

Integrated Assessment

Integration was attempted through working as a research team, with information exchange between participants being facilitated by the Project Leader through workshops and personal contact. All participants used climate warming scenarios developed for MBIS, though in some cases, modifications were done (e.g. a different interpolation of climate data). Successful examples of cross-disciplinary collaboration include application of a) the basin runoff scenario in the levels and flows study and the tourism study, b) the forest fire scenario in the forest yield model, forest industry study, and the study on furbearers, c) permafrost information in the settlement development study to assess risk, and d) permafrost, ice and water level scenarios in the energy study.

There were also three modelling exercises that attempted to address indirect implications of multiple impacts on the region. These also used outputs from other MBIS activities as inputs to their models.

Yin (Environment Canada and University of British Columbia) developed a Land Assessment Framework to assess the implications of climate change for achieving regional development goals. The framework included the use of remote sensing imagery, GIS, and a goal programming model. The model minimizes deviation from defined target levels for agriculture, forestry and other resource uses. These targets were based on rankings of land use goals provided by stakeholders. Using impacts results from one of the climate warming scenarios obtained from other MBIS projects, one scenario was assessed by this model. Results showed that spruce production goals would not be reached, and soil erosion loss would exceed the target because of expansion of agriculture.

Huang (University of Regina) took a slightly different approach, developing a multi-objective programming

model. The model optimizes economic, forest cover and other attributes, subject to a number of constraints, including wildlife habitat preservation and soil erosion limits. Four scenarios were considered: low and high growth in agriculture and commercial forestry, and low and high replacement of forest land by agriculture. The latter two scenarios were included in response to the forest yield decline projected by **Hartley and Marshall**. In all cases, agriculture expansion could occur within constraints imposed by other resource users, but in the latter two scenarios, the decline in forestry remains.

Lonergan et al. (University of Victoria) developed an economic model and combined it with a community survey to address potential implications on the two economies of the region, wage-based and non-wage (traditional harvesting) activities. This was a multiregional input-output model, which produced estimates of employment impacts. The model was applied to a scenario of expansion of oil production in the Beaufort Sea, based on **Anderson et al.** Results from a case study of the Pedzeh Ki First Nation (Wrigley, NWT) suggest increased short term wage employment in the community business and personal services sector, but concerns were raised regarding potential community disruption if these employment opportunities would be located outside the community. Given the changing political situation due to land claims and other events, implications for aboriginal lifestyles could not be determined. This requires considerably more research.

Review of MBIS by University of Texas

As part of a review of sustainable development case studies from several countries, **Dyer and Stewart (University of Texas, Austin)** examined the research and consultation process within MBIS. Although it did not directly concern a planned economic development, MBIS was included because its attributes were seen as being consistent with successful sustainable development, such as stakeholder involvement and asking "what if" questions. The authors concluded that most stakeholders supported the MBIS process, which has received international interest, but important concerns were noted by some of the aboriginal participants:

a) it wasn't clear that aboriginal knowledge had been given the same weight as "outside" knowledge,

b) direct contact with local stakeholders had not been frequent enough, and

c) the MBIS research agenda was too rigid to allow for local stakeholders' input.

Overall, however, positive stakeholder response outweighed the negative. The MBIS process was generally seen as open-ended and participatory, and that MBIS was able to get people accustomed to the idea that "global warming" was their problem. Suggestions for improving the process were consistent with those expressed during the MBIS Final Workshop round tables. (See below)

Other Canadian and International Contributions

Fassnacht (University of Waterloo) described a new method for estimating travel time of suspended sediments through stream channels in the Mackenzie Delta. **Gan (University of Alberta)** compared different approaches for estimating snow cover for the entire Basin, suggesting that estimates can be provided from satellite imagery (passive microwave), but that there are still difficulties in obtaining data during cloudy days.

An impact study of the warm summer of 1992 in northern Germany was presented by **Toth (Potsdam Institute of Climate Impacts, Germany)**. New multinational initiatives from the International Arctic Science Committee were described for two regions: the Barents Sea (**Kuhry and Lange, University of Muenster, Germany, and IASC Global Change Programme Office, Finland**), and the Bering Sea (**Weller, University of Alaska-Fairbanks, United States**). Reports from the IASC projects are included in Section 11 of this document.

8. Round Table Discussions: Stakeholders Responses

At the MBIS Final Workshop, round table participants were asked if the scenario of impacts, as described by MBIS, would make a difference to their visions of the future, and if so, how should the region respond? Participants included stakeholders from governments, aboriginal organizations and the private sector.

a) Interjurisdictional water management

Panellists presented a full range of views on the certainty of climate change scenarios and the sense of urgency associated with the issue from **"the changes are not in the future; they are happening now"** to **"the MBIS raised the level of awareness and debate in Alberta about climate change and water resources management... the appropriateness of the current level of science and hydrology in being able to predict the future with confidence is uncertain, and in the short term there will be no immediate change or difference in addressing water management."**

Most of the panellists cited recent examples of sig-

nificant changes in regional water resources. Some felt that the impacts of those changes were being felt right now and they confirm part of the science. The examples include:

- Glaciers at the head of the Arctic Red River have been observed to have significantly retreated in the period between 1948 and 1986. It has not been determined what has caused the retreat but it follows the general trend of glacial retreat observed elsewhere along the western cordillera of Canada.
- Great Slave Lake experienced 1 meter (3 to 4 feet) lower levels during 1994/95.
- 1994/95 water levels and flow conditions in the Mackenzie River region reached the bottom of the natural envelope of highs and lows in a sixty-year period. Are we reaching the bottom limit of the variability envelope?
- Mills Lake (located west of Great Slave Lake) is drying; invading willows had to be burned so that waterfowl could continue to use the lake.
- Tourism operators have not noticed a longer season for their activities because of warmer temperatures, but a shorter one. August water levels and flows (during 1994 and 1995) were lower and clients could not get out on the land.
- Grayling are difficult to find.
- An 11 percent surcharge had been applied to electricity bills in the region in 1995. There was not sufficient water to meet the power demand from hydro-electric generating and a switch to more costly thermal generating was necessary.

The Northwest Territories have always been very concerned about the signs of change in the rivers. Initially, the changes in the Mackenzie river were thought to be due to the Bennett Dam in British Columbia, and pulp mill and Oil Sands development in Alberta. For example, regulation and hydro-electric development led to changes in flow; in winter flow was up to generate power and in summer it was down. **Robert McLeod (Northwest Territories Renewable Resources)** reported that in the Peace-Athabasca delta, changes in water quantity were attributed primarily to the Dam, but the changes to the Slave River delta were less clear. In the final analysis of the Northern River Basins Study, it was agreed that the Bennett Dam was a large part of the problem, but climate change accelerated the effects of the Bennett Dam on the river system.

The rate of climate change is important. **Dean Arey (Inuvialuit Game Council)** noted that if any scenarios lead to major, rapid and irreversible change within an individual's life span, on marine and terrestrial habitats, there will be major impacts since 70 to 80 percent of the Inuvialuit people live off the land and rely on fish, whale, and caribou. How much time they have to adapt to the severity of the effects will have a direct bearing on his people. If the changes occur over centuries, then his people will be able to adapt; changes of nature have always been slow and the Inuvialuit have been able to alter their lifestyles. However, if the changes occur over decades or less, it will be harder to adapt. Also, the scenarios will not be occurring as a singular event but occurring at the same time and compounding the effects upon Inuvialuit land, animals, water, and therefore Inuvialuit people. **Karen LeGresley Hamre (Gwich'in Interim Land Use Planning Board)** noted that the Gwich'in have adapted to natural phenomena before; there have been floods and forest fires in the area. Traditionally, the response has been to move to different areas. However, even if we can demand some reduction in the greenhouse gases, there will be a lot of adaptation in lifestyles and planning systems because of climate change. In putting together the land use plan for the Gwich'in settlement area, the science says "... you can't take the climate as given." Plants, animals and fish will not stay the same. Another "big, variable element" has been introduced and it will make planning difficult for the large, permanent blocks of land that have been set aside within the claim for traditional use. Those blocks of land may change significantly enough that they are no longer suitable for those particular activities.

Issues of management and climate change were also raised by **Brian O'Donnell (Environment Canada)**. If we are touching the bottom of a natural variability envelope, how is that impacting on us today? And if we are going to be regularly at the bottom of the envelope, at lower water levels, how might we project some managerial actions in the future? Are the causes natural variability; some result of human activity, climate change; or a combination? Do the scenarios of climate change make a difference on our future view of interjurisdictional water management? Perhaps the answer is "yes", partly because there is a new method for managing interjurisdictional water through the Mackenzie River Basin Transboundary Waters Master Agreement. It defines general water management principles for six jurisdictions including Canada, the NWT, Yukon, B.C., Alberta and Saskatchewan where water is shared in an equitable manner and the aquatic ecosystem is protected. It will be a new mechanism for responding to

interjurisdictional water management and broader ecosystem management issues brought about by changing water regimes and resource availability.

b) Sustainability of ecosystems

Scenario impacts on vegetation were described by MBIS participants, but it has been considerably more difficult to determine implications for terrestrial and freshwater wildlife. Round table panellists added their own observations on effects of the recent warming trend. There was a fish kill in 1989 attributed to high water temperatures in Beaver Lake and areas downstream from Great Slave Lake **(George Low, Fisheries and Oceans Canada)**. Catch and possession limits had to be implemented that year. Other examples include a decline in rabbit populations in the South Slave area **(George Kurszewski, Metis Nation)**, and changes in plant growth after fires **(Charlie Snowshoe, Gwich'in Interim Land Use Planning Board)**. For many other cases, however, it was difficult to separate the effects of any climate trends from other causes and from natural variations within ecosystems. There could be synergistic effects as well. For example, contaminants found in water and fish could affect responses to climate change.

Scenarios of wildlife impacts were suggested for barren ground caribou and grizzlies. Changes in vegetation could lead to shifts in locations of caribou calving grounds, which may change their exposure to predators **(Ron Graf, GNWT Renewable Resources)**. **Kevin McCormick (Environment Canada)** described potential scenario effects on migratory birds

The discussion on potential actions included some familiar themes, such as the need for improved communication between scientists and stakeholders, a better understanding of the information needs of decision makers, and greater appreciation of traditional knowledge. The need for proactive adaptation was emphasized by **Maurice Boucher (Fort Resolution Environmental Working Committee)**, and **Cam McGregor (Alberta Environmental Protection)** expressed some confidence that the region could adapt successfully.

Specific proposals provided by the panellists were:

- increased ecosystem monitoring through a partnership between scientists and Aboriginal communities, incorporating western science and traditional knowledge;
- expanded use of co-management bodies, with representation of Aboriginal communities and other levels of government, ensuring that all information is used in decision making;
- that adaptive strategies, including adjustments of commercial quotas and catch limits, should consider the potential for new species to emerge that might be better suited to changing habitats; and
- continue with settlement of land claims, which would ensure local control for sustainable harvesting.

Ecosystem sustainability was an important theme not only for resource management, but also for economic development and sustainability of native lifestyles. In that context, **Maurice Boucher** stressed the need to recognize the role of values and value judgements in decision making. **Cam McGregor** and **Kevin McCormick** noted, however, that science-policy communication is also affected by public awareness of what the problems are, and what the choices are.

Climate change is a complex issue that requires local response and sharing of information. **Charlie Snowshoe** added that even land claims agreements might not be enough for Northerners to respond effectively to global issues like climate change, ozone depletion and nuclear accidents like Chernobyl. He concluded that this situation is like many of the other issues that Northerners are grappling with, and that solving global warming problems involves a learning process for everyone.

c) Economic Development

Panellists stressed that even in the next century, the old rules of supply and demand will still apply, but the region's political landscape is changing, due to recent and pending Aboriginal land claims. Economic development decisions and scientific research will have to include regional stakeholders as full partners.

Within the current operating environments of business, it is difficult for climate change to be considered in day to day operations or short term planning. **Chris Fletcher (BC Ministry of Forests)** noted that there are many other policy issues confronting forestry, such as the new BC forest practices code. **Daryll Hebert (Alberta Pacific Forest Industries, Inc.)** suggested that climate change should be added as another element in modelling work for long term planning within the forest sector, as well as within the new national Centre of Excellence in sustainable forest management at the University of Alberta. Local stakeholders in forestry have not shown concern about climate change, so it has not been factored into forestry policies, but in response to questions about incorporating uncertainty about climate change into resource development

decisions (i.e. why is climate change uncertainty different from other uncertainties), both panellists acknowledged the need to make climate change an explicit element in models used to analyze allowable forest harvests and future risks.

At the community level, climate change impacts could become important, but partnerships will be needed between communities and higher levels of government when developing management plans. **Bridgette Larocque (Metis Nation)** and **Charlie Furlong (Mayor of Aklavik)** stressed the importance of recognizing that as a result of land claims, Aboriginal people are now major land owners in the North, and future economic development and scientific research would require full consultations with these communities. **Charlie Furlong** felt that climate change is not a certainty and as a small business owner, he has no resources to invest in this issue, however, he recognized the potential long term implications of a scenario of permafrost thaw and lower water levels in his community. Long term monitoring and information exchange is important since it would make it easier for communities to adapt in a proactive way.

The Northwest Territories could reduce emissions of greenhouse gases through improved energy efficiency and conservation. **Joe Ahmad (Northwest Territories Energy Mines and Petroleum Resources)** agreed that even though regional emissions are modest, reductions would be important as a model for others to follow.

Sustainability was not directly considered in the research activities, or by the panellists, which led to a question from the audience about long term economic sustainability. In response, **Daryll Hebert** replied that since economic success is measured by demand-driven production, it will be a challenge to bring sustainability concepts into the management structure of industry, and into the marketplace.

d) Maintenance of Infrastructure

The panellists' comments were presented in the context of several decades of collective experience of planning, designing, building and maintaining transportation routes and building structures in permafrost areas within the Mackenzie River Basin. Evidence of climate warming is being experienced and is presenting challenges to maintaining existing infrastructure and design and construction of planned development. Environmental, economic and social considerations need to be addressed in the management of infrastructure in the north.

Rod Dobell (University of Victoria) commented that not only climate change, but ecological processes, social institutions, and human responses and adaptation are all in a state of flux. He suggested the concept of infrastructure can be expanded from transportation, communication, waste disposal and built environment to include emergency response systems, insurance mechanisms, monitoring and regulatory systems, education, health and social support systems. More generally infrastructure can include social and cultural institutions that pool risks and support people in times of stress and change, or govern harvesting and land use activities in a sustainable manner. He suggested possible responses to climate change might include changing design and construction standards, species conversion in forestry, fisheries or wildlife, and regulatory reforms governing land use and activity siting.

Pietro de Bastiani, (GNWT Ministry of Transportation) described potential impacts on marine, rail and road transportation infrastructure. Mobile sea ice is a barrier to shipping and warming may result in increasing tonnage of ice breakers. This has obvious implications for shipping in the Arctic. The Mackenzie River is very important for tug and barge transportation, especially fuel, to the north, and is dependant on high water conditions. Potential for lower stream flows will result in higher transportation costs.

Permafrost and ice conditions are important for all land-based transportation. Ice strips for air transport are currently experiencing erosion problems in areas impacted by fire. Permanent roads and ferry harbours are experiencing erosion damage from permafrost melting. Any changes in rates of run off, melting, and water flows would result in revising dates for cut-offs and closures of winter roads. The future development of new roads, to new mines etc., will need to be carefully assessed.

Randy Cleveland (GNWT Ministry of Public Works & Services) noted that the north depends on the cold and deals with the cold. Construction techniques are sensitive to changes in ground temperature, but a changing rate of warming surface temperatures will necessitate adaptation of new techniques.

Important considerations for siting buildings include water level changes and flushing action, slope stability and coastal erosion. As long as these are slow processes we can adapt. But these are not just engineering questions. Adaptation is connected to lifestyles, and cultures. New technologies and construction usually mean imported materials, higher costs and imported labour. The "ecological footprint" from construction in the north is very large and "sustainable construction" compatible with aboriginal lifestyles in the north needs to be considered.

Technology will change, but this alone won't mitigate the problem of global warming. Appropriate building technology will develop, and demonstration projects should be advocated. The GWNT has done little proactive work but is now looking at sustainable construction.

Alan Hanna (AGRA Earth & Environmental Limited, Calgary) participated on the panel as an engineer with work experience on pipelines in the north and in Russia and not as a representative of InterProvincial Pipelines Limited (IPL). He felt that in the short term , climate change impacts are not significant, but in the long term we have to be concerned. Generally construction in the north that is sited on bed rock is not a concern, but fine grained, ice-rich areas are thaw sensitive. Discontinuous permafrost zones would be expected to show low to high impacts, and, in continuous zones, low impact from climate change. Fires may result in mud flows and impacting infrastructures. Dams and dikes may need to be monitored and retrofitted with insulation or artificial ground cooling. Large pipelines may need to be chilled to reduce their impact on right of ways.

He expressed confidence that there is a robust engineering knowledge of how to deal with warm and cold permafrost. In response to concerns about pipeline ruptures and other potential extreme events, he responded that temperature swings are variable and we should not become alarmist about the situation. We will have to adapt, but not over-react. It would be less expensive to remedy the situation rather than to invest in large capital expenditures now.

Several questions related to sustainability were raised by the audience, including the use of alternative energy systems, consideration of climate change in long term design standards, and potential increases in the North's "ecological footprint." Panellists responded that the use of waste heat and wind energy is being looked at, there is some utilisation of passive solar technology, and energy conservation programs are being implemented. However, design standards are not being reconsidered at this time, even though it is recognized that current standards are driven by past experience and climate change introduces a new complexity. **Pietro de Bastiani** noted that new information on sea ice is not used because of downsizing and closing of various services. Some buildings are deteriorating while governments face budget reductions. In addition, there is increased demand for all-weather roads and other infrastructure that will be more costly than it was in the past and this will increase the North's ecological footprint.

Information exchanges between all parties was encouraged, including considerations for re-evaluating policy futures, codes of practice and monitoring.

e) Sustainability of native lifestyles

The subject for this discussion was the impact of global climate change on the sustainability of native lifestyles without proactive action. Research results on scenario impacts and land, water, wildlife, and economic activities, described above, were supplemented by additional studies on communities. Highlights from community studies are:

- Northern communities adapt to flooding in different ways, so future adaptation will depend on how these communities evolve in the context of other political and social changes (**Newton, John Newton Associates**)
- Northern residents provide different visions of impacts for traditional and wage-based lifestyles within a scenario of climate change (**Aharonian, University of Victoria, from Interim Report #2**),
- community members observe many environmental changes, but they process information in a different way from government departments; integration of traditional knowledge with western science requires some real connection to the lives of people in the environment under study (**Bielawski, Arctic Institute of North America, from Interim Report #2**),
- if climate change creates some wage-based opportunities that would force community members to relocate, it is possible that this would disrupt traditional harvesting activities (**Lonergan et al., University of Victoria**).

During the thousands of years since native people have been living in the Mackenzie river basin they have learned to successfully adapt to changes in environmental conditions. Changes during the last decades have started to occur at a faster pace, nomadic people settled, and young people gained more education. As **Joanne Barnaby (Dene Cultural Institute)** pointed out, the impact of a changing climate is an addition to a long list of factors that is expected to affect the livelihood of people in the North. There are not only environmental pressures on traditional livelihoods, but also social and economic ones. The traditional way of life has been dependent largely on the harvest of renewable natural resources and therefore changes that influence this resource base will directly affect people's livelihood prospects. At the same time, it is also recognized that an increasing number of native people seek their livelihoods in the wage versus the subsistence economy and this factor together with the import of goods from the outside world may decrease their reliance on the local re-

source base. With or without climate change, native lifestyles are in flux and the specific impact of a changing climate needs to be considered in this context.

The perception of local residents is that there has been a slight, but noticeable shift in the length and transition between seasons. **Don Antoine (Dene Environmental Committee, Fort Simpson)** mentioned that freeze-up occurs later and ice breakup occurs sooner than in the past. Perhaps as a consequence of thinner ice than usual and a more gradual transition between seasons, ice breakup is less forceful than in the past when violent breakups were frequent.

Water levels across the Mackenzie Basin were at an all time low in 1995, possibly as a result of less precipitation and higher evaporative loss. While on the sub-regional level, the impact of human development, such as the Bennett Dam can be very significant, overall the cause of the water deficiency in recent years was believed to be climate related. The impact on wildlife species that have significant value for the regional economy and the livelihood of people, will have direct influence on native lifestyles. For instance, the disappearance of muskrat from the Peace-Athabasca delta, as mentioned by **Whit Fraser (Canadian Polar Commission)**, is related to decreased water availability. Trapping was a major industry a few decades ago, but according to local people there are no muskrats in the area any more, therefore, people need to look for alternative sources of income, one of which may be finding a job in the wage economy.

While water shortage would be a problem on the land, the coastal communities of Tuktoyaktuk and Inuvik are expected to be at risk of flooding if a projected sea level rise occurs. Given sufficient warning and time to change, communities would be able to relocate. However, the cost of community relocation would be beyond the communities' economic capability.

Forest fire with moderation was considered a natural and beneficial force in native culture, replenishing and rejuvenating the forest. Increased fire frequency and intensity, however, can bring about more extensive habitat change that will potentially affect species composition. As **Lou Comin (Wood Buffalo National Park, Heritage Canada)** mentioned, some species such as the martin, fisher or squirrel require mature forests. Caribou may be also affected. The larger burns would mean a decreased availability of this type of habitat, and therefore, decreased population densities of species, some of which are important for the trapping and hunting industry. The impact is expected to be species specific and there is high uncertainty with respect to the adaptability of particular species to the changes that will occur.

Wildlife is critically important in the economic sense, primarily as a source of food, income and traditional clothing, but inseparable from the cultural importance for maintaining traditional systems of knowledge and identity. Changing impacts on wildlife will require that native communities adapt by modifying traditional activities, such as trapping, fishing, and hunting patterns. *Although successful adaptation has always been part of their life in the past, the predictability of the extent, duration and speed of changes made adaptation possible.* There is a real concern that if changes affecting wildlife are fast and dramatic, native communities would be left in a very vulnerable position.

Climate change impact on employment opportunities in the region is expected to be mixed. The employment picture has significantly changed in the past decades and continues to change today due to several reasons. As **Herbert Felix (Inuvialuit Game Council)** mentioned, children are receiving more "western" education than their parents and grandparents. There is improved access to local communities, and in some cases there is regular air service that people use to commute to their jobs. The decision to take up a job in the wage economy instead of trying to make a living off the land, may be linked to the success of resource harvest. If muskrat or caribou has disappeared from an area, people are likely to look for alternatives and if employment in the wage economy is a possibility, they may choose that option. All this could and does mean a loss of traditional lifestyle, an essential part of which is using resources the land and water can provide.

Panellists discussed different strategies to respond to climate change impacts. Included are measures to improve knowledge regarding the actual occurrence, severity, and impacts of anthropogenic climate change. Emphasis was also given to strategies aimed at decreasing greenhouse gas emissions and strategies to increase the success of adaptation if more serious climate change occurs.

The need for more effective partnership-building between government and native communities is a critical cross-cutting issue and was brought up in several contexts in the session. One of the most important areas of collaboration should occur in the area of integrating western science with the traditional knowledge of native people. **Don Antoine** noted that collection of information should not be seen as the end of the process, but that the knowledge and information collected should be put to use in modern management practices as well as traditional activities. For

science and resource management it means more attention being paid to understanding traditional knowledge, for government it means involving native people early on in decision-making processes, and for native communities it means more interaction between elders and young people and most importantly an understanding and respect for the traditional lifestyle.

Collection of baseline information on wildlife, water, vegetation, landforms, weather, harvest rates, social conditions, employment, and many other factors is essential in order to establish a baseline so we know if change takes place. Through baselines we can identify the pace, direction and impacts of change on other resources. As **Herbert Felix** mentioned, this information is necessary so we know what resources and values are at risk and need protection, and what is the time frame of changes. Monitoring should be a collaborative effort, relying on scientific methods and instruments, but also depending on the information and knowledge of people on the land. Traditional aboriginal knowledge is based on the experience of many generations and has a long term historical perspective that is not the case with management methods that are based on modern science. As both **Joanne Barnaby** and **Dan Antoine** confirmed, native people and elders are more than willing to share this knowledge. In terms of monitoring they are the ones on the land the most to see changes first, and they are the most affected by these changes.

People in the north also need to take responsibility for their fair share in eliminating anthropogenic causes of global warming in their own activities. As **Lou Comin** pointed out, without preventive action the situation can expected to increasingly worsen. Preventive action should involve awareness raising through educating local people and building on their creativity and ability to adapt. Results of the study should also be used to influence industry and government at appropriate fora to decrease the pressure that is contributing to climate change, showing the existing and potential costs and effects of climate change for the land and people in the North.

It is recognized that even if immediate preventive action is taken, the impact of climate change is expected to increase in the foreseeable future, requiring adaptation to changes in wildlife cycles, weather patterns, seasonal shifts and so on. Successful adaptation on the local level will require programs involving local people and more involvement from the general community in order to develop an ownership of solutions. Local people need to understand and be part of developing strategies that will make a difference on the ground otherwise there is a danger of frustration and consultation burnout. **Don Antoine** mentioned the Community Resource Management Projects (CRMP) as an example for working out solutions with hunters and trappers in an integrated management framework on the community level. Adaptation may require serious constraint by local people. For example, the community may have to make a decision against commercialization of wild game if the commercial harvest would deplete populations of increasingly vulnerable species beyond their carrying capacity.

Beyond traditional knowledge, adaptation to climate change will require training programs in order to have people with leadership and management skills in areas of highest importance. **Don Antoine** mentioned that the creation of Nunavut in 1999 will require well-trained people, but today there are very few of them. More training programs, like the one for aboriginal youth on renewable resource management at the Aurora Research Institute in Inuvik, may be necessary to prepare them for the tasks ahead.

Results of scientific research should be made accessible to the broader population in the region as one of the preconditions for more involvement and partnership building. It was emphasized that a plain language version of MBIS results should be prepared and made widely available to communities in the region.

Responding to climate change impacts may be a potentially costly exercise, especially if the impact on the North turns out to be proportionately more serious than elsewhere in southern Canada. Resources should be strategically allocated to both preventive measures and developing adaptive capacities to climate change.

The round table participants concluded that native communities in the Mackenzie Basin have been undergoing cycles of changes and adaptation for many centuries. Given sufficient time, native communities in the past found ways to accommodate and successfully adapt to gradually evolving conditions. However, the pace of changes in the last decades have accelerated and climate change is adding an additional layer of complexity to this already complex picture. Impacts are cumulative, and there is a great deal of uncertainty concerning the responsibility of climate change for symptoms seen on the ground. Nevertheless, the discussion clearly identified pathways through which climate change may affect resources native communities rely on and therefore the lifestyles of native communities themselves.

Changes in the climate and the natural ecosystem parallel socio-political developments, such as the 1999 creation of Nunavut, a new jurisdiction with its own institu-

tions and system of governance. Dealing effectively with the challenges of climate change will require a collaborative effort between the new institutions, local communities, federal agencies and international organizations. Central to these efforts will be the protection of land and its resources that are the basis of traditional lifestyles in the Mackenzie Basin.

9. Recommendations

Panellists gave their reflections on the MBIS experience, as well as the outcomes of the other five round tables. Common themes from this discussion were communication, monitoring, traditional knowledge, and collaboration.

Jim Bruce (Canadian Global Change Program, Royal Society of Canada) provided a list of specific recommendations:

- establish a co-managed Mackenzie Basin monitoring network which would include both empirical and traditional knowledge based observations, data analysis and reporting.
- watch for new opportunities as new research tools become available from other research programs (e.g. GEWEX)
- participate in impact studies on neighbouring regions (e.g. Prairies, Bering Sea Impact Study)
- provide information on MBIS to the Canadian Climate Program Board and the Canada Country Study on Climate Impacts and Adaptation
- hold follow-up workshops in the region every 2-3 years
- publish a paper on the integration process within MBIS, including lessons learned
- ensure that climate change is considered in the Mackenzie Basin Transboundary Waters Master Agreement, and
- reduce greenhouse gas emissions so that the rate of warming will slow down.

Rodney White (University of Toronto) felt that there needs to be a greater focus on risk, and not to restrict the discussion to a scenario of a doubling of greenhouse gas concentrations, since the world may experience much higher concentrations. Collaboration with stakeholders should be continued.

David Malcolm (Aurora Research Institute) agreed with the need for collaboration with other research programs, as well as for increased attention on risk analyses. Plain language reporting should be an essential component of communication, and perhaps this could be accomplished by existing institutions in the region, and by regular meetings of Northern scientists. Since governments are downsizing, this may be an opportunity for local empowerment on this issue.

After making similar statements about the need for risk analysis and reductions in greenhouse gas emissions, **Joe Benoit (Gwich'in Land Administration)** added some points about traditional knowledge and its potential role in integrated assessment with western science. The best way to do this is for cultural immersion to create greater understanding, so that scientists see things the way aboriginal people do. Regarding training, the Gwich'in and Inuvialuit just had the furthest north graduation of aboriginal students in a resource management program, but we can't ignore elders. This helps to communicate technical information between generations.

In the discussion, panellists and the audience continued exploring the main themes of communication and collaboration. The need for communicating in "plain language" , ensuring that all can understand the results, was pointed out. Information that is not clearly understandable will be ignored and thus will result in a lack of action or concern.

It was suggested that use be made of organizations such as the Canadian Climate Program, Canadian Global Change Program and the Canadian Polar Commission and that they be asked for help in disseminating messages and using the information as part of their lobbying efforts. Organizers were asked to ensure that the messages speak to all Basin residents, aboriginal and non-aboriginal from both north and south of "60".

It was noted that many important data were collected over the course of the Project and that this information should be archived for future use. A number of significant climate-related changes were found by MBIS researchers and the proposed monitoring system would help track changes as they continue. This region was cited as a bellwether of climate change for Canada.

The use of Traditional Knowledge (TK) as a monitoring/research tool was discussed. Within the aboriginal community plans are underway to develop some standards for traditional knowledge based data although scientists will have to do some work to develop a framework for using it in traditional scientific work. TK can provide local information about sensitivities at a much smaller scale than most models, and can also indicate issues that are of great concern for the stakeholders. Researchers were reminded that TK exists because lives depend on it. They

were encouraged to do research as if their lives depended on it.

There were a number of comments relating to both process and future directions for research. On the process side, it was noted that a multi-disciplinary projects such as this require a full time secretariat to facilitate exchanges of information and data. The project should also specify a common platform (such as a GIS) for data exchange. **Stewart Cohen**, MBIS Project Leader, was encouraged to write a paper describing what worked and what didn't in the MBIS process in order for other projects to build on the experience.

There were a number of suggestions for future directions for research. It was suggested that the findings be incorporated into studies of the Arctic as a whole. Another possible direction is to expand the research into an integrated study of multiple atmospheric stresses in the region. In the climate of funding cutbacks and few centrally generated pools of money for large studies such as this, it is likely that future studies in the region will have to be stakeholder driven and focused on their specific concerns such as ground water management, wildlife management, water quality and forest fire management.

Residents of the region seemed to feel optimistic that future research could be more regionally driven as opposed to the older model of southern scientists dropping in to conduct a study and then leaving. It poses a number of opportunities for collaboration in the Basin. It was pointed out that there are many scientists doing research in the Arctic and that periodic review meetings may be a useful way to encourage communication and collaboration between the myriad of scientific interests. Reduced funds for research also may encourage collaboration to obtain more bang for the buck. Some commentators would like to see more collaboration between major research projects. The Aurora Institute or other regional bodies could help facilitate collaboration.

A number of times throughout the meeting speakers pointed out that the residents of the Mackenzie Basin contribute only a small portion of Canada's greenhouse gas emissions yet they are likely to experience dramatic impacts of climate change. Residents felt that despite sociological changes in their communities, they could adapt to climatic changes as long as they weren't too rapid. Slowing the pace of climate change should be an important goal of Canada's policies.

It was noted that climate change is approaching an interesting phase. In October 1997, 160 countries will be trying to reach agreement on the next steps. Territorial, Provincial and Federal governments have been talking about climate change for the last 3 years - talking about a reasonable compromise on steps to move forward (same common objective - different pathways). This is an important opportunity. The National Action Plan on Climate Change (NAPCC) was developed in 1991, but it wasn't until 1994 that it was recognized as a national document. NAPCC has 3 steps - mitigation, adaptation, and research. It was recommended that MBIS makes a strong statement. This process will generate NAPCC2 to cover the next 5 years.

The panellists concluded that strong efforts should be made to follow up and continue collaborating with MBIS scientists to help them translate their reports to Plain Language. **Jim Bruce** recommended the following message be communicated about the results of MBIS:

1) Climate change that IPCC says is discernible is now evident in Mackenzie Basin. Climate change is happening here now.

2) Impact on people of the North will be large yet they caused little of the problem.

3) People of the North can adapt if we slow down rate of climate change.

4) There is a need to set up a system to monitor where climate change will be felt first and greatest.

The audience thanked the Project Leader for his six-year effort at leading the MBIS process.

10. Conclusion

A broad spectrum of responses to the climate change issue are needed within Canada, especially those which encourage regional stakeholder involvement. Climate change is not just about climate or energy consumption or emissions of greenhouse gases. It is also about the effects which climate change will have on the earth's ecosystems, resources and human settlements, and the need to reduce or avoid these effects. This is the "so what" question of climate change. The consequences of climate change will be unique to each region and country, and a wider range of regional stakeholders should have a role in designing national and international response strategies on climate change. Shared learning through scientist-stakeholder collaboration might be one way for reaching this goal.

1

INTRODUCTION

Objectives of the Mackenzie Basin Impact Study Final Workshop

The Mackenzie Basin Impact Study (MBIS) has been an assessment of the potential impacts of global climate change scenarios on regions and inhabitants within an extensive northern area of Canada. This six-year cooperative study represents one of the first attempts at integrated regional assessment of climate change.

This collaborative research exercise was initiated in 1990. Research plans were outlined in MBIS Interim Report #1, published in 1993. A mid-study workshop was held in Yellowknife in April 1994. Principal researchers and basin residents exchanged knowledge and evaluated progress in various study areas. This was reported in MBIS Interim Report #2. Summaries of these reports are reproduced in Appendix 4 and 5 of this document, respectively.

The MBIS Final Workshop, held in Yellowknife May 5-8, 1996, provided a forum for researchers to present their findings, and for recommendations to be discussed with stakeholders. Research results and stakeholder responses are provided in this document, the MBIS Final Report. The Workshop also provided an opportunity to sketch some first reflections on the MBIS experience. There was discussion on the evolution of the study framework and consultation process. Nearly half the three-day program was devoted to round tables on the "so what" and "what should be done" questions of climate change impacts, regional responses and recommendations. A copy of the Workshop program is reproduced in Appendix 1. A list of Workshop participants can be found in Appendix 3.

Welcoming Remarks

Final Workshop of the Mackenzie Basin Impact Study
May 6, 1996

Lorne Tricoteux
Indian & Northern Affairs Canada, PO Box 1500, Yellowknife, NT X1A 2R3

On behalf of the Department of Indian Affairs & Northern Development, NWT Region, it gives me great pleasure to welcome you all to Yellowknife for a final wrap-up on the Mackenzie Basin Study.

I note that you are calling this workshop *The Mackenzie Basin Impact Study,* rather than *Impact of Climate Warming on the Mackenzie Basin.* I appreciate your wisdom in adopting this neutral title, particularly given that the temperature outside today is about 15°C below normal.

I am pleased that this six-year cooperative study, on integrating Climate Change into the overall subject of Resource Management, has reached a stage when the scientific observations can be summarized and a set of "what if" questions can be asked and discussed. The answers to the "what if" scenarios will be of great value to those impacted by climate change in the North, whether it be government, industry or the communities.

We look forward to the results of your research to assist Resource Management agencies in the design of mitigative measures, necessary for managing development on a sustainable basis in NWT.

We all understand the benefits of long term planning for sustainable development. We only have to reflect on our current investment in environmental clean-ups to remind ourselves of the need to improve planning and to adopt different principles and approaches. More than ever before, we have an obligation to *do things right the first time.*

The success of this initiative is obviously due to the dedication of Dr Stewart Cohen, the Organizing Committee, the numerous behind-the-scene lead Research Agencies, Aboriginal organizations and communities, all of whom have supported the project, in various ways. I want to thank you all for your contributions.

I would also like to recognize the key financial sponsors: Environment Canada and the Canadian Climate Program; the Canadian Polar Commission; the Royal Society of Canada; the Science Institute of the NWT; the GNWT Department of Renewable Resources; and my own department.

I note that one of the six topics you will be discussing at the Round Tables is entitled *Native Lifestyle Sustainability.* I am happy to report we are well along with the implementation of four land claims in the NWT, and other claims are being negotiated.

Through claims "agreements" and related, new, resource management regimes, Aboriginal people have now regained the control and stewardship for the management of northern resources and the environment both in their respective traditional areas, as well as territory wide.

A research program like the one you have undertaken can only lead to additional questions, because it opens up new awareness in our minds. I trust that the results of your work will be a valuable tool when policy decisions are considered, both for the short and the long term. Your valuable contributions to successful implementation of the principles of sustainable resource development cannot be overstated. We look eagerly to the recommendations that will be coming from the workshop and the various panels.

I wish you all the best in your deliberations.

Welcoming Remarks

Final Workshop of the Mackenzie Basin Impact Study
May 6, 1996

Bob McLeod

Department of Renewable Resources*, Government of the Northwest Territories, Yellowknife, NT X1A 2L9
**Now known as Department of Resources, Wildlife and Economic Development*

Good morning. On behalf of the Government and people of the Northwest Territories, I would like to welcome everyone to the final workshop of the Mackenzie Basin Impact Study. I believe this study has achieved much more than its original objective to assess the potential impacts of climate change scenarios. These other achievements have been important to me for personal reasons and this is what I would like to take some time to reflect on.

The Mackenzie River basin has played an important role in my family history. My forefathers were traders and I have relatives in almost every community along this water system. This has its advantages and disadvantages. Most of you probably also know that the story of the Headless Valley in Nahanni is about my great uncles. Myself, I was raised in the community of Fort Providence, which is where the Mackenzie River flows out of Great Slave Lake. From my own experiences and those of my relatives, I saw and heard about the importance of this river system in providing food to the people who lived along it, a transportation route to hunting grounds and communities in both summer and winter and a playground for us as children.

As dams and industrial plants were built throughout the Mackenzie River basin, those who lived along the river, and watched it every day, saw changes in how the winter ice formed, the annual flood cycle and the fish that lived in the river. These changes were pointed out to scientists and government, who then came to study them. At first, I understood that the Bennett Dam, pulp mills and oil and gas development were the cause of these changes. By then, I was part of government and I realized that there was also no communication with communities because when I went home, I was always asked what do I do.

These observations made me realize that northern people were not partners in the study or management of this great river system and I saw that the MBIS and other similar studies were an opportunity to make some changes. To me, the greatest challenge of the MBIS was to make northerners equal partners in the study and I believe we have made some progress:

1. I see that almost one third of all the people making presentations over the next two days are aboriginal, northern residents. Six years ago, when this study began, this would never have occurred;

2. I and others have stressed to MBIS participants that northern residents have a lot of knowledge to contribute as we try to assess how our world is changing. Involving traditional knowledge was particularly challenging because there were no models to follow. Other studies, such as the Northern River Basins Study have been successful in incorporating traditional knowledge. This is the only way of knowing the state of ecosystems before changes occur. It also added significantly to scientific research as local people could tell us where the best places to take samples, monitors flow and identify trouble spots;

3. At several Working Committee meetings and workshops, I have stressed the importance of communicating with local communities on research priorities, plans and results and the value of using aboriginal languages. Not only does such communication result in identifying priorities and improving research designs but it also results in increased support for the study, which ultimately ends up in more research funding. I think the MBIS has set some examples for scientists and communities to follow on how this could be done.

The MBIS opened my eyes in showing that climate change is a much greater threat to the Mackenzie River Basin than the Bennett Dam and pulp mills. It is important to communicate this as widely as possible so that decisions on how to respond can begin.

Overall, I have been pleased with how MBIS participants have responded to the challenge of making northerners equal partners in the study. In future studies, we will go farther and I look forward to the day when I can go home to visit my parents or see some of my many relatives along the river and they can say, yes, they know what I have been up to.

Thank you.

Results and Reflections from the Mackenzie Basin Impact Study

Stewart J. Cohen

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Abstract

The Intergovernmental Panel on Climate Change (IPCC) has concluded that increased concentrations of carbon dioxide and other trace gases will lead to a warming of the world's climate. The Mackenzie Basin, including parts of British Columbia, Alberta, Saskatchewan, Yukon and Northwest Territories, has experienced a warming trend of 1.5 C this century, and there is some evidence that this has already led to permafrost thaw and lower lake levels in some areas. This does not necessarily mean that the "signal" of human-induced warming has been detected, but it does demonstrate that the Mackenzie region is sensitive to current climate variation. Scenarios of climate change, based on outputs from General Circulation Models (GCM) of the atmosphere, indicate that this region would warm by 4 to 5 C by the middle of the 21st century. What impacts would result from these scenarios?

The objective of the Mackenzie Basin Impact Study (MBIS) is to produce an integrated regional assessment of climate change scenarios for the entire watershed, including terrestrial and freshwater ecosystems and the communities that depend on them. Results are summarised from research activities sponsored by and contributed to the MBIS exercise. Some key findings are the following climate change scenario effects: 1) runoff is projected to decline slightly, with an earlier spring peak, 2) winter lake levels are projected to decline to below current minimum levels, 3) ice on the Peace River is projected to form later in the fall, break up sooner in the spring, and its upstream advance could be reduced by more than 200 km, 4) increased permafrost thaw and accompanying landslides are projected to occur in the Mackenzie Valley and Beaufort Sea coastal zone, 5) peatlands are projected to disappear from areas south of 60°N and expand in northern areas, though the rate and timing of change has not been determined, 6) forest growth rates are projected to change, with fire frequency and severity increasing, and this could reduce commercial potential and harm some wildlife species, 7) caribou could be affected by projected increases in summer temperatures accompanied by increased insect harassment, 8) the potential for wheat production would be improved but only with expanded irrigation, and 9) community impacts would vary depending on permafrost thaw rates and the nature of future economic development patterns, which could also be affected by climate change.

These and other possible changes may be outside the limits of historical experience, and so may have implications for various resource management policies, plans, and agreements. Identification of these implications requires consultation with the region's stakeholders. With that in mind, the MBIS Final Workshop includes a series of round table discussions on various issues: interjurisdictional water management, ecosystem sustainability, economic development, infrastructure maintenance, and sustainability of traditional native lifestyles.

0. Prologue: Why Study "Global Warming" Impacts?

If one was to sit on an ocean beach and watch the tide advance and retreat day after day, it would be easy to accept the proposition that this and other natural cycles will always be a powerful influence on planet earth, and that humans could not possibly alter or disrupt them. During our years and decades of life, each of us has experienced or heard about floods, heat waves, severe winters and other extreme events, and then everything returns to normal, so it is logical to assume that extremes may come and go, but climate itself is stable. When looking back at centuries and millennia of earth's history, with its many Ice Ages and warm periods, why shouldn't we embrace the hypothesis that climate change has happened before and will happen again regardless of what societies do? According to conventional wisdom, even if climate change happens again, this would develop very slowly, and we have a few more centuries before we have to worry about the next episode.

Against this background of widespread acceptance of climate stability, scientists have been suggesting that humans can affect climate patterns, through industrial activities, intensive agriculture, deforestation and transportation. Emissions of carbon dioxide, nitrous oxide, methane and other trace gases, combined with land use changes that reduce their absorption, have led to increases in atmospheric concentrations of these gases. The recipe of our air is being altered by 5.5 billion cooks, most of them not realizing that they are part of the kitchen staff.

After a series of scientific publications and meetings on the issue of "global warming," governments and international bodies, including the United Nations, agreed to consider this problem at the 1992 Earth Summit. One of the Summit's products, the UN Framework Convention

on Climate Change (UNFCCC), is now a part of international law, committing more than 150 nations to action. Its ultimate objective is to stabilize global concentrations of carbon dioxide and other 'greenhouse gases' at a level that does not represent 'dangerous anthropogenic interference' to the atmosphere. At issue, however, is the definition of the term 'dangerous.'

Human induced climate change (global warming) was a global scale science question when the first papers on General Circulation Models (GCM) were published in the 1960s and 1970s (e.g. SMIC, 1971). It became a policy question in the 1980s, linked to the growing interest in sustainable development and global change (WCED, 1987; WMO, 1988). With the ratification of UNFCCC, global warming became recognized as a multidimensional problem that requires multidimensional solutions. Science and policy response, mostly concerning emission reductions, have received considerable attention from governments, non-government organizations (NGO), universities and the private sector. The research effort, however, has not given equal attention to "the other dimension" of global warming – adaptation to the projected impacts of climate change scenarios.

The Intergovernmental Panel on Climate Change (IPCC) has traditionally looked at the policy aspects of climate change as a mitigation problem. Working Group III of IPCC focuses on mitigation options and their various economic and technical constraints (IPCC, 1995). Through Working Group II, there is some recognition that climate change impacts may be important, but the connections between impacts and policy response have not been fully explored. This connection ultimately leads to questions about proactive adaptation to scenarios of climate change.

Adaptation, the other dimension of global warming, is only a sideshow, while the mitigation debate continues. This is reflected in IPCC Working Group III reports and the literature on integrated assessment (IA) of climate change. The IPCC considers IA to be a modelling approach that enables stakeholders to make informed decisions about mitigation options (Carter *et al.,* 1994; Weyant *et al.,* 1996). The IPCC Second Assessment includes a comparison of 22 integrated assessment models (IAM) designed to address mitigation (Weyant *et al.,* 1996). This is encouraged by the conventional thinking that impact costs for most countries are known to be less than 2% of GDP in a 2xCO_2 climate change scenario (usually assumed to occur around 2050 - 2100), with the exception of the small island states or other areas vulnerable to sea level rise (see Pearce *et al.,* 1996). Impacts description and valuation is considered to be a weak area in IA (Parson, 1995).

Regional impact assessment is a complex multidisciplinary research challenge. To make matters even more difficult, we are considering an assessment not of an observed climatic event (such as the 1994 and 1995 forest fire episodes in the Northwest Territories) but of a theoretical warming of the earth's climate by increased concentrations of greenhouse gases. There are many uncertainties associated with the data and methods used to construct scenarios of a future warmer world, and some have argued for the use of analogues (Glantz, 1988; Kearney, 1994) as an alternative to scenarios based on climate model simulations, population projections, and other forecasting tools. There is little doubt, however, that if climate warming occurs, the earth and its people will feel its effects through a variety of "pathways" and "filters," including land and water resources, and the impact assessment needs to account for these.

What makes this concern even more urgent is the recent conclusion by the IPCC that recent climatic trends cannot be ascribed completely to "natural" forces (IPCC Second Assessment Report, 1995). ***The human influence on the earth's climate is being felt now.***

Meanwhile, mitigation efforts are becoming bogged down. Some countries, including Canada, are pursuing voluntary programs. Several have entered into Joint Implementation initiatives, which are currently at the pilot stage (Foundation Joint Implementation Network, 1995). At the present time, however, most countries report that they won't reach their emission reduction targets (IEA, 1995) and political support for such efforts is relatively weak. If greenhouse gas concentrations continue to increase, and if current concentrations are already affecting the climate system, the world may have to face the other dimension sooner, rather than later.

1. Introduction to MBIS

The Mackenzie Basin Impact Study (MBIS) is a six-year collaborative research effort to assess the potential impacts of climate change scenarios on the Mackenzie Basin region of northwestern Canada. Initiated by Environment Canada in 1990, with funded research commencing in 1991, the MBIS has attracted participants from governments, universities and the private sector. Meetings and workshops have been held, two interim reports have been published, five issues of the MBIS Newsletter have been distributed, and efforts have been made to maintain contacts with regional stakeholders, including Aboriginal Peo-

ples. Proceedings from the MBIS Final Workshop are published in this volume as the MBIS Final Report.

When the idea of a large integrated regional impact assessment was first proposed in 1990, initial reaction ranged from excitement to fear. Some felt that this was a timely exercise that would be attractive to regional interests. Others were afraid that it couldn't be managed, and would fall far short of being "integrated." There were even suggestions of a political nature, positive and negative, reflecting attitudes influenced by various events not related to this venture (e.g. previous funding patterns, changing institutional roles).

After a year of planning and five years of research and consultation, the MBIS now completes its last phase. The Final Workshop is intended to be a forum for presenting final results, and soliciting reaction from stakeholders through a series of round table discussions. "What if" is confronted by "so what." At this time, it is possible to anticipate some of the "what if" answers, but what will the "so what" answers be? Will stakeholders agree that the exercise has produced "useable" and "policy relevant" science? Will integration have been, or appear to have been, achieved? Will MBIS say something new to the region and will its recommendations be acted upon?

The purpose of this review of MBIS is to look at both the development and application of the study framework, key results from the various sponsored and contributed research activities, and lessons learned from coordinating an integrated assessment and communicating its progress to stakeholders.

The "so what" answers provided by participants at the MBIS Final Workshop are found in Section 3 of this volume.

2. Development of Study Framework

The MBIS framework developed in two distinct phases. The first was the pre-research phase, from 1989-1992. The second was the research and consultation phase, 1992-present, in which researchers and stakeholders shared their views on both science and policy issues specific to the Mackenzie Region. A chronology of events in the history of MBIS, including a selected listing of meetings and regional visits by the Project Leader, is shown in **Table 1**. The timing of Working Committee (WC) meetings is included, as well as a tabulation of the number of research proposals approved at each meeting.

2.1 Pre-research phase, 1989-1992

The first vision of the MBIS framework was a progression from scenarios to first order studies (physical and biological sciences), second- and third order studies (social sciences), to integration exercises (economic modelling, primarily an input-output approach). Linkage with stakeholders and policy issues was not explicit. The main concern was to create scenarios that would be followed in a consistent manner by all study participants. There was also a need to identify the main sources of data and expertise for this region, and to attract and incorporate these into the program.

Table 1. MBIS Chronology

DATE	EVENT
89/12	First Draft of MBIS Proposal
90/04	Preliminary Approval of Draft Proposal
90/04-06	internal funding from Environment Canada, first regional consultations
90/10	Organizational Meeting of MBIS Working Committee (WC), Yellowknife
90/11	WC #1, Edmonton
91/02	WC #2, Vancouver; proposal review criteria adopted; 4 proposals accepted
91/03	Meeting with NWT and Aboriginal Representatives, Yellowknife; visit to Rae Lakes, NWT
91/10	WC #3, Calgary; 5 proposals accepted
92/02	WC #4 and Integration Workshop #1, Edmonton; 6 proposals accepted, policy issues identified; Green Plan funding officially announced beginning FY1991/92
92/08	visits to Norman Wells, Inuvik, Tuktoyaktuk
92/12	WC #5 and Integration Workshop #2, Edmonton; 3 proposals accepted, linkages between scientists identified
93/03	**Interim Report #1**
93/04	visits to Edmonton, Yellowknife, Lutsel k'e
94/01	Joint Meeting with GEWEX participants, Saskatoon
94/04	Mid-Study Workshop, Yellowknife; 1 proposal accepted
94/11	**Interim Report #2**
95/03	**Summary of Interim Report #2**; visits to Edmonton, Yellowknife, Inuvik, Aklavik, Fort Smith
95/08	Project Leader assigned to University of British Columbia
96/03	participation in Denendeh Environment Gathering, Yellowknife
96/05	Final Workshop, Yellowknife
97/01	**Final Report**

It was clear from the outset that even though funding would be over a 5-year (later changed to 6-year) period, the MBIS budget would probably not be able to support new monitoring programs or the creation of new data bases from scratch. It was also clear that MBIS would be at least partially dependent on cooperative research ventures with other parties, including ongoing research and monitoring activities that may or may not have been developed with climate change in mind.

2.1.1 Creation of management structure

In order to define the research agenda and its participants, it was necessary to create an infrastructure that would mirror the current Mackenzie Basin research community, as well as those with broader research and policy interests in climate change. In October 1990, the MBIS Interagency Working Committee (WC) was established, and agreed to the following statement of goals:

"The Mackenzie Basin Impact Study will define the direction and magnitude of regional scale impacts of global warming scenarios on the physical, biological and human systems of the Mackenzie Basin, using an integrated multidisciplinary approach. The study will also identify regional sensitivities to climate, inter-system linkages, uncertainties, policy implications and research needs. Study results will be published and made available to all interested parties" (Cohen, 1993).

The WC included members from various levels of government, as well as aboriginal organisations (**Table 2**). It met on 5 occasions during 1990-1992. Several members which were active participants during this phase withdrew during the research phase. One of these was Esso Resources, which contributed financial support to MBIS in 1991/92.

One of the WC's main activities was proposal review and ranking. Thirty-six proposals were reviewed during 1991-92, and whole or partial support granted to 18 of them (Cohen, 1993). Four additional projects were brought into MBIS during 1993-94, two of these after the MBIS Mid-Study Workshop (Cohen, 1994a,b). Some research activities were contributed to MBIS but not directly funded by the MBIS budget. There were also research activities led by Atmospheric Environment Service (AES) staff and supported by internal funds.

In terms of funding, MBIS committed approximately \$770K to support a total of 19 external (i.e. investigators not based at the Atmospheric Environment Service of Environment Canada) research projects during the 6-year period (**Table 3**). In addition, there were 11 projects contributed from other sources at no cost to MBIS.

Much of the funding came from the Government of Canada's Green Plan (1991-1995). Additional direct funds were provided by the AES of Environment Canada, Indian & Northern Affairs, and other government departments. The equivalent cost of contributed research, internal support from Environment Canada, in-kind support from various sources, and co-sponsorship of MBIS funded research was probably of equal magnitude to directly funded projects.

By the time MBIS is completed, around \$180K will have been spent on travel, workshops and publications, including the May 1996 Final Workshop. These are shown in **Table 4**.

The total direct MBIS expenditure for the 1990-1996 period was around \$950K, of which around 80% was used to support research outside of the AES. The total direct expenditure is relatively small for a 6-year interdisciplinary research effort with many collaborators. Of this total,

Table 2. MBIS Interagency Working Committee

FEDERAL	PROV./TERR.	PRIVATE SECTOR	ABORIGINAL
Agriculture	Alberta Env. Protection	Esso Resources Ltd.	Dene Nation
Environment	Alberta Research Council		Gwich'in Tribal Council
Fisheries & Oceans	British Columbia Hydro		Indian Assoc. of Alberta
Indian & Northern Affairs	NWT Energy, Mines & Petroleum Resources		Inuvialuit Game Council
National Defence	NWT Renewable Resources		Metis Association of NWT
Natural Resources (former Energy, Mines & Resources, and Forestry)	Yukon Territory Renewable Resources		
Tourism			

Source: Modified from Cohen (1993). NWT = Northwest Territories.

Table 3. MBIS Budget: Direct Research Expenditures and Sources of External Contributions

Lead Investigator/Agency	Topic	Duration	MBIS Support ($ 000)	Other In-Kind & Financial Support
Aharonian (U. of Victoria)	Climate-society interactions, Aklavik	1992-94	0	U. of Victoria, Aklavik
Anderson (McMaster)	Petroleum production	1993-96	42	
Andres (Alberta Res. Council[1])	Peace River ice	1991-94	50	Alberta Research Council
Bayley (U. Alberta)	Peatlands	1991-96	84	NSERC[2], Env. Canada, Esso Ltd.
Benton (Pacific Forestry Centre[3])	Forestry: growth and yield, fire, pests.	1992-96	50	B.C. Ministry of Forests, NSERC, NWT Fire Centre, Alberta Forest Service, Nat. Res. Canada
Bielawski (Arctic Inst. of North America)	Traditional knowledge, Lutsel k'e (pre-proposal)	1992-94	22	Lutsel k'e
Bone (U. of Saskatchewan)	a) Settlements, b) Non-renewable resources	1993-96	38	
Brklacich (Carleton)	Agriculture	1992-96	81	Agriculture Canada
Chin (BC Hydro)	Williston Lake runoff	1992-94	0	BC Hydro
Cohen (AES,[4] UBC)	MBIS Framework	1989-96	0	Env. Canada, UBC
Felton (Env. Canada)	Water management	1993-94	0	Env. Canada
Geological Survey of Canada[3]	Permafrost	1991-96	65	Nat. Res. Canada
Gong (U. Calgary[5])	Remote sensing, land	1992-94	20	
Gratto-Trevor (CWS[4])	Mackenzie Delta shorebirds	1992-95	30	Env. Canada
Huang (BCRI[6])	Multi-objective model	1994-96	0	Env. Canada
Kerr (Env. Canada)	Water levels and flows	1993-96	0	Env. Canada, GEWEX[7]
Latour (CWS[4] & NWT Renew. Resources)	Wildlife response to burns	1991-94	28	NWT Renewable Resources
Lonergan (U. Victoria)	Resource accounting, socio-economic scenarios	1991-95	87	U. Victoria, Esso Ltd.
Lonergan (U. Victoria)	Two economies, Wrigley	1994-96	35	Env. Innovation Program, Pedzeh Ki
Maarouf (AES[4])	Geese	1993-96	0	AES[4] & CWS[4]
Majorowicz[9]	Ground temperatures	1995-96	0	Env. Canada
Melville (Sask. Research Council)	Thermal habitat for freshwater fish	1992-95	40	Sask. Research Council
Newton (U. of Toronto)	Community response to floods	1992-94	08	Emerg. Prep. Canada, Aklavik, Fort Liard
Rothman (AES[4] UBC)	Forest economics	1995-96	0	Env. Canada, UBC
Smith (AES[4])	Climate change scenarios	1991-93	0	Env. Canada
Soulis (U. Waterloo)	Basin runoff	1992-94	30	GEWEX[7]
Wall (U. Waterloo)	Tourism	1991-95	25	Tourism Canada
Wein (U. Alberta)	Veg. response to fire	1991-94	10	NSERC[2]
Welch (DFO[8])	Fisheries data base	1991-93	24	U. Manitoba, DFO[8]
Yin (AES[4] & UBC)	Land assessment	1992-96	0	Env. Canada, UBC
6-YEAR TOTAL			769	

Notes: *1=now at Trillium Engineering, Edmonton. 2=Natural Science & Engineering Research Council. 3=Natural Resources Canada. 4=Atmospheric Env. Service (AES) or Canadian Wildlife Service (CWS), Env. Canada. 5=now at U. California-Berkeley. 6= BC Research Institute, now at U. Regina. 7=Global Energy & Water Cycle Experiment. 8=Dept. of Fisheries & Oceans. 9=Northern Geothermal, Edmonton.*

Table 4. MBIS Administrative Budget

Activities	Duration	MBIS Support ($000)	Other Support
Atm. Env. Service core group (computers, travel, etc.)	1990-97	50	Env. Canada, U.B.C.
Newsletters, Interim Report 1	1992-96	10	Env. Canada
Other travel (Working Ctte., community visits)	1990-95	20	Env. Canada, Indian & Northern Affairs, other
Mid-Study Workshop & Interim Report 2 (includes travel support for students, aboriginal reps.)	1994	45	Env. Canada, Indian & Northern Affairs, Royal Society of Canada, NWT-Ren. Resources, Science Inst. Of NWT[1], Canadian Polar Comm.
Final Workshop & Final Report (same as Mid-Study)	1996	55	Mid-Study sponsors plus Alberta Environmental Protection
6-YEAR TOTAL		**180**	

NOTES: *1=now Aurora Research Institute, Inuvik.*

around $700K originated from the Green Plan, with the remainder obtained mostly from Environment Canada, other government departments, Canadian Global Change Program of the Royal Society of Canada, Canadian Polar Commission, and the grant provided by Esso Resources in 1991. The level of donated research and in-kind contributions has been a source of great satisfaction, and it is clear that MBIS has benefited from this. This type of funding arrangement, however, inevitably leads to significant co-ordination problems, and this has affected the level of integration, as well as communication with other scientists and with stakeholders. Volunteerism can only accomplish so much. We will return to this and related issues near the end of this overview.

Since integration was a research goal, a small Integration Sub-Committee was established in 1991 and met during 1991-92. Its members were drawn from the MBIS core group in Environment Canada (Cohen, 1993), the WC, and a subset of investigators whose proposals were approved by the WC. Some of the discussion focused on the relative merits of different modelling approaches. What was not considered at the time was large Integrated Assessment Models (IAM), since these tools were still in their early stages of development and were unknown to this group. One important suggestion that came out of these discussions was the need for "integration workshops" or some exercises that would enable MBIS participants to appreciate linkages across disciplines, as well as with policy issues. MBIS even received an unsolicited proposal to organize and facilitate workshops of this kind, and it was subjected to review by the WC, along with the various research proposals.

2.1.2 Review of proposals

MBIS received a wide range of proposals, from physical, biological and social sciences. Some were to initiate research activities. Others were requests for joint funding of ongoing projects in other government departments so that these could continue despite pending budget cuts. Others came from academia and consulting firms, but these also included proposals for adding on to research that had already been initiated elsewhere for other reasons. This broad mixture of topics, proponents, and proposed funding arrangements, required a multi-criteria approach to proposal review. Good science alone would not be sufficient. At a meeting in 1991, the WC developed criteria for ranking research proposals (**Table 5**).

Although there was no weighting assigned to these, several were seen as of particular importance. These were "doability," applicability to the study area, linkage with crit-

Table 5. MBIS Criteria for Proposal Review

- suitable for spatial extrapolation
- time integrative
- "doable" within time and resource limitations
- applicable to the study area
- addresses research gaps and provides linkage with international programs
- linkage with critical regions and with other MBIS components
- merit and benefits to Canada's Northern people
- leverage of other funds
- sub-tasks essential to MBIS
- involvement of Northern people where applicable

ical regions, and whether sub-tasks were essential. Meeting the other criteria, especially those concerning Canada's Northern people, were highly desirable, but the WC had to be satisfied that the proposal would help MBIS meet its objective. The WC did include aboriginal representation, and their input to this process was extremely valuable, particularly as the MBIS moved on to the next phase — research and consultation.

2.2 Research and consultation phase, 1992-1996

Two integration workshops were held in 1992. The first focused on the "vertical" dimensions. What were the important policy issues that might be relevant to a climate change impact study of this region? Senior managers from Environment Canada, Prairie Farm Rehabilitation Administration, Alberta Forestry, Alberta Environmental Protection, and the Renewable Resources Department of the Northwest Territories were invited to share their perspectives with MBIS researchers in a one-day workshop. The second concerned "horizontal" integration, or the challenge of linking scientists from different disciplines in a common framework.

2.2.1 Vertical integration workshop

The "vertical integration" workshop was held in February 1992. Its purpose was to identify policy concerns related to global warming, in effect establishing "targets" for study participants. The workshop resulted in the identification of 6 main policy issues:

a) interjurisdictional water management

b) sustainability of native lifestyles

c) economic development opportunities

d) buildings, transportation and infrastructure

e) limitation (mitigation) strategies, and

f) sustainability of ecosystems.

With the exception of the fifth target, these represent concerns related to adaptation. Each of these were discussed at length in Cohen (1993), and the various MBIS activities were placed in the context of each of the 5 adaptation issues. It is important to note, however, that around half of the MBIS projects had been selected before this workshop took place.

2.2.2 Horizontal integration workshop

The second integration workshop was held in December 1992. Its purpose was the identification of data requirements of study participants, and to identify linkages between the various study activities. Each investigator was asked to indicate his/her information needs, and this was shown in a large matrix (Cohen, 1993). MBIS participants could also use this matrix to identify potential "clients" for their work.

In practice, some interaction took place among the various investigators, but there could have been more. There were even some inconsistencies in the climate scenarios used, even though there was considerable discussion about these throughout 1991-1993. Control from the Project Leader was relatively loose because of resource constraints and the widely scattered locations of MBIS participants. A full time project secretariat was not part of the budget, and perhaps that would have helped, but it would certainly have made the exercise more expensive.

2.2.3 Interim Report #1

As a follow-up to these workshops, Interim Report #1 was produced in March 1993 (Cohen, 1993). It contained an overview of the study framework, results of the 1992 workshops, description of scenarios and research activities accepted into the MBIS program. Several contributed research papers were included, such as a review of potential impacts on sea ice, and a detailed description of Mackenzie Basin hydrology.

This 163-page document provided the foundation for MBIS participants and other interested parties to see how the overall program was developing. The 2-page executive summary from this report was reproduced in an issue of the MBIS Newsletter, which was distributed throughout the region. This information was picked up by the research community, but there should probably have been additional methods used to communicate with stakeholders. There is no substitute for personal contact. Although there were visits to the region by the Project Leader throughout the program (**Table 1**), as well as by some MBIS investigators involved in field work, some stakeholders continued to express dissatisfaction with this process.

2.2.4 Mid-study workshop and Interim Report #2

The MBIS Mid-Study Workshop was held in April 1994. This event attracted around 120 participants. MBIS investigators gave progress reports, and these were supplemented by contributed papers from the biennial Northern Climate Workshop, an event co-sponsored by Environment Canada and Indian & Northern Affairs. There were also two evening public sessions on traditional ecological knowledge and on the MBIS program. The Mid-Study Workshop concluded with a Round Table discussion on progress. Most of the papers, and notes from the round table dis-

cussion, were published in the 500-page MBIS Interim Report #2 (Cohen, 1994a) and in a companion summary document (Cohen, 1995).

Throughout the workshop, and during the Round Table, concerns were raised regarding integration and communication with stakeholders. Even after the discussions on integrated assessment, there was still a feeling that the pieces of MBIS were not going to fit together, and the exercise was "southern-driven" rather than of real benefit to the region. In addition, some aboriginal people, either directly or through non-government organizations, made two specific complaints: a) models and surveys should not attempt to characterize a "typical" native response to questions about goals, nor should there be any assumption that such views would be similar to those of Indian & Northern Affairs or any other government agency, and b) they were not consulted enough about the research and none of the principal investigators were aboriginal.

The Project Leader and others had some responses to these criticisms (Kertland, 1994). First, it was noted that expectations of MBIS had changed considerably since its launch in 1990, and that instead of being a narrowly focused study on climate impacts, it had expanded into the broader context of sustainable development. Second, study investigators were southern-based because the NWT government and aboriginal organizations had indicated during the pre-research phase (e.g. 1991 meetings) that they were not ready to participate as climate change research partners, though they were interested in the process. There were some actions taken to respond to criticisms about integration and communication, including the addition of two more projects (Cohen, 1994b). A regional speaking tour was also arranged during March 1995, and with expanded availability of electronic mail, bulletins could be distributed more frequently. It was obvious that the use of Newsletters themselves yielded very limited success in reaching stakeholders.

Integration is a difficult challenge, and this had been discussed at Working Committee meetings from the very beginning of MBIS. There was no consensus on the best approach to accomplish "integrated assessment." It was decided, therefore, to pursue several integration exercises, including

a) the 1992 workshops,
b) various types of integrated modelling (Huang, Lonergan (2 projects), Yin),
c) other research activities that combine information from bio-physical and socio-economic disciplines (e.g. Benton, Rothman, Bone, Brklacich, Felton), and
d) the 1994 and 1996 workshops.

2.2.5 The MBIS Final Workshop, May 1996

At the May 1996 event, MBIS investigators presented final reports on their activities. This was also an opportunity to sketch some first reflections on the MBIS experience. There was discussion on the evolution of the study framework and consultation processes. Most important, nearly half the 3-day program was devoted to 6 round tables on the "so what" and "what should be done" questions of climate change impacts, regional responses and recommendations. The key element was stakeholder participation in these round tables, for this was a highly visible measure of the success or failure of MBIS to demonstrate a viable scientist-stakeholder collaboration on this topic.

3. Scientist–Stakeholder Collaboration

There are two aspects which require further elaboration: 1) coordinating the scientists, and 2) communicating with stakeholders. These are objectives that most people genuinely want to achieve, and some important and unanticipated problems arose in each case.

3.1 Coordinating the scientists

Despite the workshops and other activities held during this exercise, several obstacles to interdisciplinary research became significant challenges. This affected both the transfer of data between investigators, and the integration process.

At the outset, several investigators placed a fair bit of confidence onto the flexibility of Geographic Information Systems (GIS) to handle data sets produced by other tools (including other GIS). This has not been an easy process, and in hindsight, it may have been better to have specified a common GIS platform. It is fair to say, however, that this would have led to some objections from various participants since they had already invested time and resources into developing their own data bases and expertise on whatever system they happened to be using. This may be a technological problem that will continue to persist until GIS data bases acquire a more uniform format

Integrated assessment exercises (including models) were supposed to provide "targets" for output generated by sectoral studies. Incompatibilities turned up here, too. For instance, investigators working on economic impacts could not provide the data required for the resource accounting framework being set up by another MBIS partic-

ipant. As a result, this exercise would narrow its focus, and not include many of the sectoral impacts addressed in other MBIS activities (e.g. agriculture, forestry, tourism). Similar problems surfaced with another exercise—the land assessment framework. Perhaps the best approach would have been for the integrated modellers to specify their data requirements, in a very explicit manner, before the selection of other projects. Fulfilment of such requirements could have been added to the review criteria for proposals submitted to the WC. This would not have guaranteed success, however, because these models have generally not been used in climate change impact assessments before, and there would be no way of knowing with certainty that their data requirements could be met.

It should also be noted that communication among investigators outside of MBIS meetings/workshops was dependent on their initiative. The widely scattered nature of the MBIS group precluded frequent meetings, so once all the participants had been identified and their plans disclosed, investigators were on their own. They were encouraged to share information, but this was not forced by the Project Leader, especially since many investigators were either part time (including students) or were volunteering their results to the collaborative. Lack of resources for full-time support (either from the MBIS budget or co-sponsors) sometimes resulted in participants dropping out prematurely to take on other opportunities. Stronger direction from the Project Leader would not have been possible without additional resources to support full-time investigators (such as private scholars/consultants) and a full-time Secretariat.

3.2 Communicating with stakeholders

Since 1990, the Project Leader held formal and informal meetings with stakeholders, mostly in Alberta and the Northwest Territories. This was supplemented by visits to 8 communities in the Northwest Territories (**Table 1**). In addition, several MBIS projects included field work in these and other communities throughout the study area. The various MBIS meetings and workshops described above, however, were held in the NWT capital of Yellowknife, or in larger centres in the south (particularly Edmonton). The reasons for this were primarily economic, since most of the investigators were based in the south, and the meeting site had to be easily accessible. Most native stakeholders had no problem with travelling to Yellowknife or the south as long as travel support was provided. In some cases, however, aboriginal organizations did not have the people available, given the small size of their support staffs and the many other issues that these same individuals were involved in. Over time, however, this began to change.

Rapid institutional changes took place during this period, and its impact on communication was noticeable. In 1990, only one aboriginal group, the Inuvialuit, had a settled land claim and an established infrastructure, including a full time secretariat which coordinated Inuvialuit participation on resource management boards and joint activities with other parties. The Inuvialuit Game Council became the main contact for MBIS, and consultation was able to continue uninterrupted throughout the MBIS program. Other groups did not have settled land claims, nor did they have full time staff focusing on environment or resource management issues. By the time the Mid-Study Workshop was held in 1994, two more groups had settled Land Claims, and other organizations had full time environment managers on staff. During this 4-year period, there was frequent turnover in representation from these other groups which hampered effective consultation. The current situation is considerably more promising, and at the 1996 Final Workshop, 11 of 28 Round Table panellists were aboriginal or from aboriginal organizations.

Certain others have been more difficult to reach, including some federal and provincial government agencies. Climate change is an issue embraced by some and avoided by others, depending on their mandate, jurisdiction, and perceptions (beliefs) about the need for a proactive response to a "theoretical" global-scale problem. Much of the consultation effort in MBIS focused on interested parties in Alberta and the NWT because their relationship with the study area was direct and obvious. These parties were easy to identify, and they came forth readily to provide their views. The NWT government also became a research participant and co-sponsor early in the program, while the Alberta government agreed to co-sponsor the MBIS Final Workshop. Other provinces/territories are also within the study area, but the Mackenzie Basin is not as important to them as other regions. One exception is British Columbia, which is the upstream jurisdiction in this watershed. A stronger effort should have been made here earlier, and there were increased efforts during 1995/96 at attracting stakeholders from British Columbia to the May 1996 Workshop.

4. Some Results from MBIS and Contributed Research

If climate warming occurs, governments and their constituents will need advice on how to adapt to the new climate. Since decision making occurs in an environment

where different stakeholders compete for resources, any response options will have to account for trade-offs between these various interests. Land and water use patterns today represent the result of historic and current compromises between these various interests, combined with knowledge gained from research and personal experience. At the scale of most current climate change impact assessments (e.g. grid sizes larger than 2° latitude x 2° longitude), land in a grid cell is not necessarily assigned to a single optimal use today, so it is unlikely that this would be different in the future. The assessment, therefore, should not restrict itself to changes in physical capability to support a particular activity (e.g. crop production).

The objective of MBIS is to provide an integrated regional assessment of scenarios of climate warming for regional stakeholders and the scientific community. As a high latitude watershed, the Mackenzie Basin has been seen as an area that might benefit in certain ways by a warmer climate. These include a) longer growing season for agriculture, b) greater productivity for forestry, c) longer ice-free season for navigation, d) reduced energy demand for space heating, e) longer summer tourist season, and f) reduced cold weather stress on infrastructure. Taken individually, economic impacts could be quantified, and these might show substantial benefits for the region. Other factors need to be considered, however, and some of these may constrain the potential benefits. This list includes: a) current use of land for subsistence hunting and trapping, b) current system of land transportation, much of which is based on a stable ice and snow cover for winter roads, c) current ranges and habitats of wildlife, which underpin conservation plans and native land claims, and d) scientific uncertainty which hampers anticipatory responses to projected beneficial conditions.

Potential negative impacts of climate warming must also be considered, because they may offset possible benefits. Examples are: a) increased erosion due to permafrost thaw, b) increased frequency and severity of forest fires, c) extension of mid-latitude pests and diseases into high latitudes, and d) reduction of habitat suitable for cold climate species of vegetation and wildlife, including freshwater fisheries.

One theme that has clearly emerged in the MBIS is that climate is a complex agent of change. Although scientific and political discussions have tended to focus on ***atmospheric*** change, the land and its people will likely experience climate warming through changes in streamflow, water levels, ice and snow cover, permafrost, plant growth, wildlife patterns, fire, pests and diseases. Some changes may occur gradually while others may come in the form of large steps or new extremes.

The linkage between changes in air temperature and regional socio-economic concerns is largely through these landscape 'filters.' Biophysical changes are what people will notice before they pay attention to climate statistics. Has the winter road season changed? Is anything new with the caribou migration? Are current fire management strategies still working satisfactorily? What is the status of permafrost along the Mackenzie Valley and the Beaufort coastal zone?

Some preliminary indications of landscape and socioeconomic impacts for the scenarios being assessed by MBIS are shown in **Tables 6** and **7**, respectively.

Runoff for the Basin was obtained using a square grid model (Soulis *et al.,* 1994), and for the Williston subbasin with the UBC Watershed Model (Chin and Assaf, 1994). Although increased runoff was anticipated (e.g. see Miller and Russell, 1992), this does not appear to be the case for the GCM-based scenarios (Canadian Climate Centre or CCC, Geophysical Fluid Dynamics Lab or GFDL (R30 version)) for the Basin as a whole. Only the composite analogue scenario shows an increase. Newton (1994) has therefore concluded that scenario spring flood risks for vulnerable communities may not be that different from current climatic conditions. It may be that a more significant problem could be lower water levels during fall and winter (Kerr, this volume), which could affect fisheries and reduce the probability of spring flooding in wetlands and deltas.

What is not clear as yet is the implication of hydrologic and landscape changes on water management agreements currently being negotiated by various governments (Felton, 1994). Peace River ice cover, for example, will be affected by both temperature changes and changes in outflow from the Bennett Dam at Williston subbasin (Andres, 1994; Andres and van der Vinne, 1995). This may not be the final word on runoff impacts, since the Global Energy and Water Cycle Experiment (GEWEX) is pursuing a research programme in the Mackenzie (Lawford, 1994).

It would appear that the other main threats to the Mackenzie landscape are a) accelerated erosion caused by permafrost thaw, especially in sloping terrain and the Beaufort Sea coastal zone (Aylsworth and Egginton, 1994; Solomon, 1994; Aylsworth and Duk-Rodkin, this volume; Dyke *et al.,* this volume), b) increased fire hazard (Kadonaga, 1994, this volume), c) change in climate conditions that influence the development of peatlands, leading to reductions in Alberta and Saskatchewan, and expansion in the

Table 6. MBIS Summary of Landscape Impacts of Climate Warming Scenarios

PARAMETER	DETAILED IMPACTS
Permafrost thaw occurs, but rate of change varies with site	• thaw would occur primarily in discontinuous zone • seasonal active layer would increase • rate of thaw in wetland areas lags behind other sites • slopes and Beaufort Sea coastal zone may experience accelerated erosion
Water Supply changes slightly, with earlier spring peak; seasonal minimum water levels reduced to below current extreme low levels	• annual Basin runoff changes -7% to -3% in GCM-based scenarios, +7% in composite analogue scenario • increased precipitation offset by increased evapotranspiration in many subbasins • spring snowmelt peak begins up to 1 month earlier • longer snowmelt season, lower peak in some subbasins (including Williston/Bennett Dam) • lower levels during November to March at Great Slave and Great Bear Lakes
Peace River Ice Cover reduced in duration and extent	• ice cover reduced by up to 4 weeks • upstream progression of ice reduced by up to 200 km • runoff reduction (or reduction of discharge from Bennett Dam) would offset effects of temperature increase on ice cover
Soil Capability for Agriculture increases, but yields may not increase without expanded irrigation	• increase in availability of marginal and suitable land for spring seeded small grains and forages due to longer growing season and frost free period • decrease in soil moisture supply • current cereal varieties may mature too rapidly under higher temperatures
Pine Weevil Hazard increases	• increase in temperature-based pine weevil index • low elevation sites particularly vulnerable • non-temperature factors not yet included
Peatlands' locations shift	• loss of sites in Alberta and Saskatchewan • new sites develop in lower Mackenzie, south of Mackenzie Delta • rate of change has not been determined
Forest Growth and Yield may change due to higher temperatures and increases in Fire Weather Index (FWI) and Pine Weevil Hazard Index	• median FWI for four scenarios corresponds to change of -15% to +81% in burned area • changes in productivity and yield vary by species and tree age • regional productivity would decline

NOTES: Summarized from Cohen (1993, 1994) and this volume. Additional information on Peace River ice from Andres and van der Vinne (1995)

lower Mackenzie (Nicholson *et al.,* 1994, this volume; Gignac *et al.*, in preparation), and d) invasion of new pests and diseases from warmer regions (Sieben *et al.,* 1994). These landscape impacts could lead to changes in plant succession (Wein *et al.,* 1994). Impacts on wildlife appear to be mixed (Gratto Trevor, this volume; Latour and Maclean, this volume; Brotton *et al.,* this volume; Maarouf and Boyd, this volume).

First-order and second-order impacts eventually lead to others which are considerably more difficult to address. Will land claims or water resources agreements be affected? Would it be appropriate to artificially maintain historic water levels in the Peace-Athabasca Delta within this scenario of climate change? Could there be new conflicts over land use, especially if agriculture expands northward to take advantage of improved soil capability to support crop production (Brklacich and Curran, 1994; Brklacich *et al.,* this volume)? What might be the effects on parks and other protected areas (Pollard and Benton, 1994)? Could climate change affect the economics of commercial forestry (Rothman and Herbert, this volume) or oil and gas production in the Beaufort Sea (Anderson *et al.,* this volume)?

Expressing socio-economic impacts in monetary

Table 7. MBIS Preliminary Summary of Socio-Economic Impacts of Climate Warming Scenarios

SECTOR/LOCATION	DETAILED IMPACTS
Commercial forest harvest would be reduced unless there are increased expenditures on fire and pest control	• improved growth of hardwoods offset by increased fire frequency • growth of softwoods declines • average tree age declines • potential implications for annual allowable cut and rotations • direct and indirect implications for forest dependent communities in Alberta and British Columbia portions of the Basin
Wheat production could improve but expanded irrigation services would be needed	• potential increases in wheat yield from elevated CO2 levels offset by shorter grain filling time and less favourable soil moisture • use of longer season spring wheat cultivar provides only minor improvement • winter wheat cultivar may provide improved yields in the south • expanded irrigation would overcome projected deficits in soil moisture
Tourism would experience mixed impacts	• little impact at Nahanni National Park from projected minor changes in streamflow; extended season for water-based recreation would provide economic benefits to communities near the Park • increased Fire Weather Index (fire frequency and severity) could affect runoff, landscape character, visitor safety • potential losses to Bathurst caribou herd would affect sport hunting north of Great Slave Lake
Community vision of impacts depends on vision of lifestyle	• response to flood hazard varies by community, according to the interplay of individual, community and government responses • several NWT communities in areas of high risk for subsidence and landslides from permafrost thaw • significance of landscape impacts depends on whether community maintains subsistence lifestyle, or switches to wage economy • a case study of Wrigley NWT concludes that if climate change encourages expanded development of oil and gas, economic impacts would be small, but positive, unless workers are forced to relocate to obtain employment

Summarized from Cohen (1994) and this volume. Additional information from Wrigley case study obtained from Lonergan et al. (1995).

terms is difficult, but some information is provided for agriculture, forestry, energy, and some aspects of tourism. In the latter case, for example, water-based recreation at Nahanni Park, is expected to benefit from the longer summer, but this could be offset by the threat of increased fire (Staple and Wall, 1994). There is no assessment here on the potential costs of increased fire or fire protection for tourism. Impacts on sport hunting may turn out to be more serious (Wall *et al.,* this volume).

Community impacts could be quantified, but the effects of climate warming scenarios may vary depending on whether a traditional aboriginal lifestyle of hunting and trapping is maintained, or a shift to greater reliance on the wage economy occurs. Aharonian's (1994) case study of Aklavik shows that residents can provide detailed visions of both "futures." In their view, community vulnerability to climate warming scenarios will change if their lifestyles change. This may parallel circumstances that could be experienced in some developing countries during the next several decades.

In providing an integrated assessment, MBIS has undertaken some exercises in model development. One activity is on the development of a Mackenzie Basin input-output model. This has been used to determine impacts of changes in energy (oil and gas production) on the region's employment and economic productivity (Lonergan, 1994; Lonergan *et al.,* 1995). There was also a community survey in Wrigley, in the Mackenzie Valley region, which examined whether lifestyle changes, within the context of "Two Economies," could be affected by climate change. In this case study, a warmer climate is assumed to encourage offshore oil and gas development in the Beaufort Sea. The effect of this scenario on communities could be positive, unless people are forced to relocate to obtain employment. Other forces, particularly in regards to land claims issues, may have far greater impacts than a scenario of fossil fuel industry expansion (Lonergan *et al.,* 1995; this volume).

Other modelling exercises include the integrated land assessment framework or ILAF. Its purpose is to compare changes in land capability with stakeholders' goals in order to identify possible land use conflicts in a climate warming scenario (Yin and Cohen, 1993, 1994; Yin, this volume). Results suggest that potential expansion of commercial agriculture would lead to increased soil erosion (Yin, this volume). Additional activities in multiobjective programming (Huang *et al.,* 1994; this volume) also focus on potential expansion of agriculture.

Impacts and responses will not be felt by individual sectors in an isolated manner. A unit of land (at a scale comparable to GCM output) is not likely to end up becoming exclusively devoted to one kind of land cover or use. This set of research activities represents a first step at addressing some important cross-cutting issues at a scale comparable to regional stakeholders' interests.

5. New Questions for Stakeholders

In order to make the connection between "what if" and "so what," it is suggested that some "real world" questions be framed in the context of "scenarios." In any study of "futures," such as climate change impacts or sustainable development planning, we may be faced with determining implications of scenarios of change. What follows are four scenario cases from MBIS, linking some first-order and second-order impacts with management and policy concerns in this particular region.

i) Scenario case 1: Changing Water Levels

The Mackenzie Basin is a very large high latitude watershed, 1.8 million km^2 in area. It includes several large lakes and rivers, freshwater and coastal deltas, and extensive wetlands and peatlands with many small, shallow lakes. One sub-area of considerable interest is the Peace-Athabasca Delta, which includes habitat for fish and migratory waterfowl.

Within global warming scenarios derived from GCM outputs, it appears that runoff in much of the Basin may decrease (Soulis, 1994). This would result in lower river and lake levels (Kerr, this volume). Ice cover on the Peace River would be reduced (Andres and van der Vinne, 1995).

Although water use in this region is modest, in-stream flow requirements for ecological purposes are very important for fish, birds and other wildlife. The Peace-Athabasca Delta has been experiencing low water levels, and concerns have been expressed regarding the viability of habitat for fish and wildlife. This concern resulted in several major research initiatives, including the Peace-Athabasca Delta Technical Studies (PAD). PAD includes experiments at creating artificial ice dams in order to induce flooding for ecological purposes (PAD Technical Studies Committee, 1994).

PAD and other efforts were initiated because of the assumption that the Delta's water level problems were caused by the operations of a hydroelectric facility located upstream. The region's climate was not considered to be a direct factor. This view, however, may be changing, as the current warming trend in the region becomes more noticeable (Skinner and Maxwell, 1994).

Would stakeholder response to changing water levels be different if they believed that the cause was natural climatic variability rather than a hydroelectric facility? What if the cause was "global warming?" What if it was a combination of all three? If this scenario was to lead to any changes in water management, what would the financial implications be?

ii) Scenario case 2: Changing Land Capabilities

Agriculture in the MBIS region is confined to the southern third due to the relatively short growing season. There are potential sites farther north, but these are limited by cold temperatures. A warming scenario could enable small grains to be cultivated on an additional 10 million hectares of land (Brklacich and Curran, 1994).

This land, however, is currently being used for other purposes, primarily for forestry and wildlife habitat. The latter is particularly important to native communities, which depend on them for food, and for manufacturing articles made of skins and furs (e.g. clothing). Much of this activity is part of the traditional lifestyles of the region's aboriginal peoples, and is recognized as a "non-wage" economy. There is aboriginal participation in the "wage" economy, and expansion of agriculture and other activities from the south could provide additional employment opportunities. If land is converted to these other activities, however, would traditional activities be affected? Just because there may be a change in land capability doesn't necessarily mean that land conversion would immediately follow. Such decisions would depend on stakeholders' views being resolved through the process of policy making in the region, and this needs to be recognized in the IA, whether or not an IAM is used. Current global scale IA and IAMs have had difficulties in providing a reasonable representation of policy, especially adaptation measures (Parson, 1995).

Within MBIS, there are two IAM exercises underway which focus on changing land capabilities (Yin and Cohen, 1994; Yin, this volume; Huang *et al.,* 1994; Huang, this

volume). Both utilize stakeholder inputs and the results of first-order impact studies, but the models are different, so the results are different. A third picture of the future is represented by the approach taken by the "Two Economies" study (Lonergan *et al.*, 1995; this volume). Since there is no consensus on the "best" IAM for such purposes, all three experiments have gone ahead. There are a number of problems related to data availability which could bias the analyses. Other concerns include compatibility of Geographic Information Systems and reliability of stakeholder surveys and census data. Here is an opportunity for IA to look at a very important aspect of impacts and adaptation, with the same cross-cutting comparisons as the modelling community currently uses in the mitigation arena (e.g. Weyant *et al.,* 1996).

iii) Scenario case 3: Changing Fire Weather

Fire is a normal component of the boreal ecosystem, and within Canada's Northwest Territories, around 1 million hectares burn in an average year. In 1994, there were 630 fires, covering approximately 3 million hectares (McLeod, personal communication). That year was around 1-1.5°C above average, with below average rainfall during the growing season. By contrast, a 4-5°C increase is described within global warming scenarios for the MBIS region derived from GCMs (Cohen, 1993).

Territorial fire fighting resources were severely tested in 1994, and almost 25% of the fires were not fought. The costs for some fires reached CAN$1.2 million each, compared with a historic maximum of CAN$0.5 million (McLeod, personal communication). 1995 was also a bad year. Several communities had to be evacuated, and there were problems in Northern Alberta as well.

In a climate change scenario, years like 1994 and 1995 could become more common. The "average" fire season would include a higher Fire Weather Index, resulting in increased potential area burned (see Kadonaga, 1994, this volume). What effect would this have on fire management? This question cannot be considered in isolation from land management objectives, since these objectives would be used to set priorities for selection of fires to fight. Community protection would always be a high priority, but what about wildlife migration routes? What if commercial agriculture, tourism and forestry expand into the region? Just because there could be increased fire potential doesn't necessarily mean that more forested land will burn, or be allowed to burn. As with the case of possible land conversion, any changes in fire management policy, including associated financial implications, would depend on changes in both fire potential, land use and stakeholders' views.

iv) Scenario case 4: Effects of renewable resource impacts on non-renewable resource development

One interesting aspect that is beginning to emerge is how decisions regarding responses in the energy industry may be affected by impacts on renewable resources. In this scenario, climate change is seen as having a negligible direct effect on exploration and production operations (despite sea level rise, sea ice changes, permafrost thaw and associated landslides). However, if climate change affects the boreal and tundra ecosystems (including forest growth, wildlife habitats, fire frequency, etc.), would regional stakeholders alter their views on future energy developments? This relates to the additional uncertainties created by climate change impacts (Anderson *et al.,* this volume), and the juxtaposition of the formal wage and informal non-wage economies in this region (e.g. Lonergan *et al.,* 1995, this volume). The latter may be significantly affected by climate change, and it isn't clear at the moment whether this would encourage or discourage expansion of the wage economy. Aboriginal people want access to both economies, so the challenge is to design a response strategy that meets this goal.

If the non-wage economy is at risk, could this lead to greater restrictions on industrial growth, or would there actually be an acceleration of industrial development, but at the expense of a decline in the non-wage economy, and traditional aboriginal lifestyles? What would happen to forestry, park management, and other renewable resource based activities?

Each of these four cases includes potential economic and social costs and benefits which may not be captured by sectoral assessments, or by available continental/global scale IAMs. There are financial and policy implications as well, which may affect regional and national climate change strategies (e.g. scenario of land conversion from forest to cropland). If the UNFCCC is going to achieve its objective of preventing "dangerous anthropogenic interference" of the atmosphere, a greater effort should be made to incorporate the impacts/adaptation dimension into assessments of climate change.

6. Lessons for Others Who Dare to "Integrate"

Climate is a complex agent of change. If global warming occurs as projected, its effects will depend not only on the direct impacts on land and water resources, but also on

how technology, economies and societies change over time. This represents a significant research challenge, but the potential magnitude of global climate change is too important to ignore, even with the many uncertainties associated with such projections.

This kind of research challenge needs an integrated approach, with stakeholders and scientists working together, sharing knowledge and experiences. Integration with stakeholders is possible, but it is not an easy process. This review of 6 years of MBIS history suggests some lessons that may be appropriate for future attempts at integrated regional assessments of climate change impacts:

a) Selection of integration exercises requires additional criteria before acceptance by the assessment's review committee, including explicit specifications of data needs and commitments to assist in communication between study participants.

b) A full time secretariat would be a significant asset. Resources should be set aside for this function, but it should not be at the expense of supporting research and stakeholder consultation.

c) There has been considerable attention given to Geographic Information Systems (GIS) as an analysis tool with tremendous potential . For exercises such as this, GIS could become very important. However, a common platform for GIS should be established as early as possible. Compatibility with this platform should be one of the criteria for acceptance into the assessment. This could involve setting up a Home Page on World Wide Web, but this option would require additional resources (as part of the secretariat's function?), and there would be questions of access, confidentiality and security.

d) Since many available analytical tools (models, etc.) are based on statistical relationships derived from current observations, investigators may need to obtain data from outside the study area, so as to include climatic conditions that may resemble the climate change scenario (i.e. a spatial analogue). Investigators must be aware, however, that the use of spatial analogues brings in additional uncertainties to the analysis.

e) Stakeholder collaboration is a major challenge, and should not be underestimated. Provision should be made for this during the pre-research phase. This could also become one of the secretariat's functions. The potential rewards, however, will be worth the effort.

f) There is no substitute for personal contact with other scientists, as well as with stakeholders. Electronic mail will help, but frequent informal meetings should be encouraged and supported.

g) There is no single best way to integrate knowledge from different disciplines. Although some favour the IAM or other modelling exercises, these should be complemented by direct interaction between scientists and stakeholders so that local knowledge can be part of the debate about climate change responses.

Another comment relates to the notion that research can provide useful information for decision makers, even though little is known about how such information actually is applied, especially in planning and policy making. What can be said is that these activities involve many actors. There is no single individual that will take scientific information and change the way policy "buttons" are pushed. Producing better information for decision making about climatic change, or sustainable development, is not enough. Stakeholders need to be part of the production of this information. This will increase the probability that this information will be used.

The cases from the Mackenzie Basin Impact Study illustrate how climate change may have indirect but profound impacts on land cover, regional resource exploitation, and consequently, national strategies for climate change adaptation and mitigation. There are many gaps and methodological challenges that will remain upon its completion, but important lessons are being learned, and new questions are being identified. These new questions have come to light because of collaboration with stakeholders outside of IAM activities, but within the study's overall integration framework. This framework is composed of modelling and non-modelling approaches, which draw on sectoral studies and local scientific and stakeholder knowledge.

Current estimates of impact costs cover only a limited set of issues. IA could do more. If IA in general, and IAMs in particular, are going to become attractive to a broad range of decision makers, they cannot be done in isolation from them. Debate about climate change should not simply involve stakeholders in mitigation (i.e. limitation of greenhouse gas emissions). There are many more actors that could become involved, and they should not be left out. In the accelerating rush towards building the "perfect" IAM, perhaps some effort should be devoted to improving our ability to "walk." This walk, or new paradigm for IA, would include: a) consideration of regional impacts and adaptation, b) linkage with existing resource

management instruments and policies, c) identification of indirect impacts when the focus is on places, rather than sectors, and d) incorporation of local knowledge into the analysis.

Climate is a complex agent of change acting concurrently with other forces of change. Others have argued that global warming will be a relatively minor agent compared with future technological, demographic and political changes, yet there is something disquieting about the power of the atmosphere to influence the availability of life's building blocks – water, food, other renewable resources, shelter and mobility. If society is going to face a climate scenario beyond historic precedent, we need to mount a much broader effort to understand what this might mean in a human, sustainable development context. This is an important challenge for IA, and one which should receive much more attention than it does now.

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2

REPORTS FROM ROUND TABLE SESSIONS

Introduction to Round Tables

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The purpose of the round table discussions was to enable stakeholders to provide their views on the results of the MBIS exercise, and to identify possible responses for the scientific, management, and policy communities with interests in the region. Climate change is a multidimensional challenge, and there may be different points of view about the science of climate change, the science of climate change impacts, and the application of such information by various stakeholders. Our intent was for the round tables to serve as a forum to air these views, so long as the discussion was relevant to the regional dimensions of climate change impacts and possible responses.

There were 6 round tables during the workshop. The first 5 were on specific policy concerns:

- interjurisdictional water management,
- ecosystem sustainability,
- economic development,
- maintenance of infrastructure,
- sustainability of native lifestyles.

The 6th was given a broader mandate to consider recommendations.

During the first 5 round tables, panellists were asked to respond to the following questions:

Question #1: Given the climate change impacts scenario described by MBIS and related projects, what is your view of the region's future, assuming the region does not respond proactively to climate change? In other words, does the scenario make a difference to your vision of the future?

Question #2: What responses to this impacts scenario should be considered in the region?

Time was provided for discussion with the audience, which included many of the researchers participating in MBIS, as well as other stakeholders and observers..

For the round table on recommendations, panellists were asked to address the following:

Question #1: What lessons about regional impacts of climate change, and about the organization and execution of impact studies, have been learned from the MBIS experience?

Question #2: What are your recommendations on how the results from MBIS should be used a) in the region, and b) in other parts of Canada?

Question #3: What are your recommendations for future actions on climate change impacts?

Reports are provided for each of the round tables by their rapporteurs. Several panellists also contributed prepared statements, which are reproduced in Appendix 2.

Round Table #1: Interjurisdictional Water Management

Rapporteur: Linda Mortsch

Environment Canada, Burlington

Chair: Jim Bruce, Canadian Global Change Program and Canadian Climate Program Board, Ottawa
Robert McLeod, GNWT Renewable Resources, Yellowknife
Brian O'Donnell, Environment Canada, Edmonton
Karen LeGresley Hamre, Gwich'in Interim Land Use Planning Board, Inuvik
Dean Arey, Inuvialuit Game Council, Inuvik
Terry Zdan, Alberta Environmental Protection, Edmonton

The context for the Round Table discussion on interjurisdictional water management was set by the Chair, Jim Bruce, by sharing the following perspective. If the framework convention on climate change (FCCC) fails to limit the amount of greenhouse gases going into the atmosphere, then we will have serious global problems. The scientific research for the MBIS has used $2xCO_2$ in the atmosphere as the basis for the assessment question: what would be the impact of a 2x CO_2 climate? At present, the increase of all greenhouse gases in the atmosphere is equivalent to a 50 percent increase in CO_2. above preindustrial levels. The FCCC may be judged a success if it prevents greenhouse gas concentrations from reaching $3xCO_2$; doubling of CO_2. may be very, very hard to avoid.

The Intergovernmental Panel on Climate Change (IPCC) has concluded that "...the balance of evidence suggests a discernible human influence on global climate". This conclusion was reached through a rigorous review of modelling research on the forcing of greenhouse gases and aerosols on the climate system and a correlation with measured temperature changes globally and the distribution of changes regionally and in the vertical. The largest changes in temperature have occurred over central and northwestern North America and eastern Siberia. It is reasonable to assume that the kind of warming seen over the last two decades in the Mackenzie River Basin is part of the signal of global warming from greenhouse gases and what is happening is a foretaste of the future and the trend is likely to continue.

From a review of the water resources posters at this workshop, research in the Mackenzie Basin has identified:

- very dry conditions in the Peace-Athabasca delta and those conditions are likely to continue with fluctuations from year to year;
- projections of lower minimum river flows with implications for navigation, wildlife habitat, and hydro power production;
- complex ice regime changes with impacts on winter transportation and flooding; and
- anecdotal evidence of warmer air and water temperatures and more sediments in the water due to land slides.

Given their knowledge of the Mackenzie Basin and MBIS research, the panelists were asked to discuss two questions. Their responses are summarized below as well as subsequent questions and answers.

What difference do the climate change scenarios make to water management, and lives and lifestyles?

All five panelists agreed that the climate change scenarios are important and that they will have an affect on the region, lives and lifestyles. For example, the regions of the Inuvialuit and Gwich'in are water-based landscapes and lifestyles, where changes in water are important to trapping, settlement, wetlands, waterfowl, and tourism. The panelists presented a full range of views on the certainty of climate change scenarios and the sense of urgency associated with the issue from "the changes are not in the future; they are happening now" to "the MBIS raised the level of awareness and debate about climate change and water resources management...the appropriateness of the current level of science and hydrology in being able to predict with confidence the future is uncertain and in the short term there will be no immediate change or difference in addressing water management."

Most of the panelists cited recent examples of significant changes in regional water resources. Some felt that the impacts of those changes were being felt right now and they confirm part of the science. The examples include:

- Glaciers at the head of the Arctic Red River have been observed to have significantly retreated in the period between 1948 and 1986. It has not been determined what

has caused the retreat but it follows the general trend of glacial retreat observed elsewhere along the western cordillera of Canada.

- Great Slave Lake is experiencing 3 to 4 foot lower levels.
- Current water levels and flow conditions in the Mackenzie River region are reaching the bottom of the natural envelope of highs and lows in a sixty-year period. Are we reaching the bottom limit of the variability envelope?
- Mills Lake is drying; invading willows had to be burned so that waterfowl could continue to use the lake.
- Tourism operators have not noticed a longer season for their activities because of warmer temperatures, but a shorter one. August water levels and flows are lower and clients cannot get out on the land.
- Grayling are difficult to find.
- An 11 percent surcharge has been applied to electricity bills in the region. There is not sufficient water to meet the power demand from hydro-electric generating and a switch to more costly thermal generating was necessary.

The Northwest Territories have always been very concerned about the signs of change in the rivers. Initially, the changes in the Mackenzie river were thought to be due to the Bennett Dam and pulp mill and Oil Sands development. For example, energy production led to changes in flow; in winter flow was up to generate power and in summer it was down. Robert McLeod reported that in the Peace-Athabasca delta changes in water quantity were attributed primarily to the Dam but the changes to the Slave River delta were less clear. In the final analysis of the Northern Rivers Study, it was agreed that the Bennett Dam was a large part of the problem but climate change accelerated the effects of the Bennett Dam on the river system.

The rate of climate change is important. Dean Arey of the Inuvialuit noted that if any scenarios lead to major, rapid and irreversible change within an individual's life span, on marine and terrestrial habitats, there will be major impacts since 70 to 80 percent of the Inuvialuit people live off the land and rely on fish, whale, caribou. How much time they have to adapt to the severity of the effects will have a direct bearing on his people. If the changes occur over 500 years, then his people will be able to adapt; changes of nature have always been slow and the Inuvialiut have been able to alter their lifestyles. However, if the changes occur over 5 to 10 years, it will be hard to adapt. Also, the scenarios will not be occurring as a singular event but occurring at the same time and compounding the effects upon Inuvialuit land, animals, water, and therefore Inuvialuit people. Karen LeGresley Hamre noted that the Gwich'in have adapted to natural phenomena before; there have been floods and forest fires in the area. Traditionally, the response has been to move to different areas. However, even if we can demand some reduction in the greenhouse gases, there will be a lot of adaptation in lifestyles and planning systems because of climate change. In putting together the land use plan for the Gwich'ín settlement area, the science says "... you can't take the climate as given." Plants, animals and fish will not stay the same. Another "big, variable element" has been introduced and it will make planning difficult for the large, permanent blocks of land that have been set aside within the claim for traditional use. Those blocks of land may change significantly enough that they are no longer suitable for those particular activities.

Issues of management and climate change were also raised by Brian O'Donnell. If we are touching the bottom of a natural variability envelope, how is that impacting on us today? And if we are going to be regularly at the bottom of the envelope, at lower water levels, how might we project some managerial actions in the future? Are the causes natural variability; some result of human activity, climate change; or a combination? Do the scenarios of climate change make a difference on our future view of interjurisdictional water management? I have to side with "yes", partly because there is a new method for managing interjurisdictional water through the Mackenzie River Basin Transboundary Waters Master Agreement. It defines general water management principles for six jurisdictions including Canada, the NWT, Yukon, B.C., Alberta and Saskatchewan where water is shared in an equitable manner and the aquatic ecosystem is protected. It will be a new mechanism for responding to interjurisdictional water management and broader ecosystem management issues brought about by changing water regimes and resource availability.

Other panelists, Terry Zdan and Robert McLeod, also felt that the Mackenzie River Basin Transboundary Waters Master Agreement was important. The Northwest Territories is downstream from B.C., Saskatchewan, Alberta, and the Yukon. Upstream changes affect the region. The Northwest Territories recognizes the importance of water management and wants to have transboundary water management agreements negotiated. For Alberta, this Agreement parallels the Water Boards in the south; it will allow Alberta to enter into bilateral water quantity and quality agreements.

Question

Jim Bruce: Models and experience to date suggest that south of 60 degrees will become drier and the Great Plains even drier whereas the very northern part of the Basin is likely to remain the same in its hydrologic balance. If the region south of the Mackenzie Basin becomes much drier in Alberta, do you have a policy in the province about diverting water from the Mackenzie system further south? Is there any position on that being developed within Alberta?

Answer

Terry Zdan: Yes. There are two elements that you raise here: one is the concern of diverting water from Alberta to the United States and internally within Alberta to the southern basins. The current policy, and it is reflected in the new revised Water Act that is being tabled and discussed in the legislature, is that Alberta will not be a party to diverting water to the United States—exporting water. Secondly, the grand schemes of the 1960's for managing water are no longer discussed.

Question

Joey Stewart (University of Texas at Austin): What has come out of the MBIS is the issue of hydrology and other important possible implications. We find in the U.S. that water is becoming a very important issue. The reserves in the U.S. are very, very low; in Mexico they are even lower. We see possible conflict between the U.S. and Canada over the issue of water. Water will probably be one of the most vital resources in the coming year, in the coming decades or longer. But I wanted to ask you the importance of water — do you see it as we do, as a very vital resource for your region, for the community?

Answer

Karen LeGresley Hamre: Certainly for the Gwich'in it is absolutely vital; it is a major basis of the whole lifestyle and the way people have lived and are wanting to continue to live. So, yes, it is vital.

Robert Mcleod: In the Northwest Territories, water is very vital to just about everything that we do, especially people in the smaller communities that live in the river basin. Water is important for drinking, for food because of the fish and for transportation; it is important for just about everything that occurs in the community. Every community in the Northwest Territories is located on a major water source, either on a river, or a lake, or the ocean. That is one of the reasons that we have always pushed for transboundary water agreements. We are very concerned that without some protection through agreements with upstream jurisdictions that there are opportunities for diversions of water that would reduce the flows and so on. So, it is vital to everything that we do in the communities.

Question

Louise Comeau, Sierra Club, Ottawa: Will the provincial Ministry take the results to the Canadian Council of Ministers of Environment (CCME)?

Answer

Robert McLeod: Our minister is very involved. He will accept the recommendations of the Northern River Basin study along with four other ministers in June. He will be assuming the chairmanship of CCME for the next year, so he undoubtedly will bring forward the results of MBIS and other environmental reports as they occur.

Question

Penny Bramwell, United Kingdom Department of Environment, London: I was quite interested that you all said that you were observing the effects of climate change. I would be interested to know how long you have been observing them and when it occurred to you that the changes that you had seen were actually due to climate change?

Answer

Brian O'Donnell: I want to clarify a point, Penny. What I was trying to convey was that we are observing water levels lower than the recent 60 or 100 years. That signal provides us with an opportunity to look at the potential impacts of what continually living at that low end or dipping below that low end might mean in terms of adaptation. As to the question of a definitive linkage between these observations of extreme events and climate change, I can only say

that they represent one more piece of evidence pointing in that direction.

Robert McLeod: I first realized the effects of climate change when I realized there were fewer mosquitoes up here. But when I think through changes—it is very difficult to determine on the Mackenzie River. The changes were almost immediate; most people felt it was a result of the Bennett Dam and it was always blamed on the Bennett Dam and probably still is. It is becoming more and more obvious that it is a combination of both. There have been some very bad fire years and climate change is becoming more obvious here as well.

Question

Maurice Boucher (Environmental Working Committee, Fort Resolution). I want to ask the panelist from Alberta how stringent are the policies for effluent discharge from the pulp mills. The studies around Fort Resolution were done when the water levels were high and there have not been any studies when the water levels were low. The greater the water quantity the more it will dilute this effluent. Since the water has been low has there been any monitoring of the effluent coming out of the pulp mills and settling in our area?

Answer

Terry Zdan: Yes. This is an area outside of my particular expertise, but as I understand the environmental regulatory service guidelines, when these pulp mills were established in Alberta they were asked to be the most proactive in terms of technology. Compared to other areas in Canada and other jurisdictions, we have pulp mills that pollute less than others. In terms of the discharges, I am not sure if these are continuous discharge facilities or whether they are timed to coincide with higher flows, similar to some municipal discharges where it can only occur at certain times of the year when the flows are appropriate in order to maintain aquatic ecosystems. The guidelines for effluent control in Alberta include protection of the aquatic ecosystem. Many systems are now being asked to be self-regulating in some respect, but there is a procedure in place to ensure that the monitoring and the water quality guidelines are being met.

What are the potential solutions?

The solutions are not easy since in many instances we cannot be specific on the impacts. The NWT will be one of the most affected regions yet it creates very little of the pollution that is the cause of the problem. The region can do its part to control emissions of CO_2 and SO_4 to set an example but the global effect will be minimal.

The hazard of high and low water levels is greater in the future than what can be expected from historical record. This will require that we plan more conservatively than in the past. Karen LeGresley Hamre suggested that in the land use planning for the Gwich'in, they will have to plan for ecological zones rather than fixed areas of use.

Risk assessment will be important to identify the causes and linkages. Mapping will play an important role.

Communication of research has to be understandable; communication of results must reach out to the larger community rather than only to the research community.

The Mackenzie River Basin Transboundary Waters Master Agreement is important to set up mechanisms to deal with some of the potential hydrologic issues of climate change. It will be a forum to look at the ecosystem or basin as a whole. Climate change will make it more difficult to maintain downstream flows at "existing levels." Certain assurances of supply should be given. Monitoring of fish and wildlife, wetlands, and water temperature will be important.

The 6-year MBIS indicates that there are requirements for more study. Many impacts were not assessed such as the marine, coastal areas to the north of the basin. What are the compounded or cumulative impacts? Is climate change happening now? The MBIS raised the level of awareness and debate on the issue of climate change. The study can be viewed as a "first" generation integrated assessment to build on in the future. Results indicate a certain direction for and magnitude of impacts. Much work remains to be done.

Round Table #2: Sustainability of Ecosystems

Rapporteur: Stephanie Irlbacher

Canadian Polar Commission, Yellowknife, NT

Chair: Edward Elliott, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado, USA.
Maurice Boucher, Deninu Ku'e Environment Committee, Fort Resolution, NT
Ron Graf, GNWT Department of Renewable Resources, Yellowknife NT
George Kurszewski, President, Fort Smith Local, NWT Metis Nation, Fort Smith, NT
George Low, Department of Fisheries and Oceans Canada, Hay River, NT
Kevin McCormick, Environment Canada, Yellowknife, NT
Cam McGregor, Alberta Environmental Protection, Edmonton, AB
Charlie Snowshoe, Elder, Gwich'in Interim Land Use Planning Board, Fort McPherson, NT.

Executive Summary

Stakeholders of the Mackenzie River Basin (MRB), represented by Aboriginal people and government agencies, were brought together to examine the scientific research concerning the potential impacts of global warming on ecosystem sustainability that was conducted over the past six years under the aegis of the Mackenzie Basin Impact Study (MBIS). Panellists were asked to evaluate the impact of this research on their understanding of the potential problems of global warming and then determine the potential application of this information to possible solutions for these problems. All panel members made observations of ecosystem responses within the MRB that were consistent with the onset of warming, but recognized the difficulties of determining whether these observations are outside the range of natural variation for the region. Clear concern was exhibited by all parties, and examples were given in the areas of fish kills, caribou behaviour and changes in the intensity and duration of the seasons. It was thought that ecosystems already weakened by pollution (e.g., radionuclides, pulp paper effluent) may be more vulnerable to climate warming.

The government and Aboriginal representatives found common understanding within the ecosystem concept of the interconnectedness of all things. A recurring theme was the need to bring together western science (WS) and Aboriginal traditional knowledge (TK) as part of an integrated approach, one which has already begun in the North with the use of co-management bodies. Similarly, an adaptive management process was discussed that included elements of monitoring, iterative evaluation of both values and the environment and action plans that were responses to the iterative evaluations. The process would necessarily be one of continual learning, as already reflected in both WS and TK. It was recognized that the development of plans must include elements of public policy and education and could not be limited merely to the management of the natural resources.

Introduction

The Sustainability of Ecosystems panel discussed observed changes associated with global warming, and suggested possible responses directed at maintaining ecosystem sustainability. Panellist's diverse perspectives meant a wide range of experiences were brought to bear on the questions under consideration. Interestingly, discussion yielded a number of shared concerns, underlying assumptions, and suggestions for action in the face of change. Suggested actions, when taken together, represent a progressive continuum of management strategies constituting an adaptive management process.

This report summarizes responses given to two questions guiding discussion (see below). The summary is organized according to common elements emerging from the responses given. Discussion centred around two overall themes: the interlinkage of traditional knowledge and western science, and flexible adaptation as the basis for addressing global warming effects.

Panellists agreed that changes are occurring; all listed specific examples of witnessed changes attributable to global warming. However, whether changes are caused by global warming or by other factors was uncertain. This uncertainty impacted on suggestions for action, resulting in a range of possibilities, with an emphasis being placed on the need for further study of ecosystem components to isolate effects caused specifically by global warming. A synthesis following from the range of responses produced an adaptive management process framework, with monitoring, ongoing evaluation, and action components.

Below are the questions used to guide discussion, and a brief explanation of key concepts informing the discussion:

1. Does your experience agree with scientific assessments of projected changes in climate, and if so, what is the future for Mackenzie Basin inhabitants?
2. How can Mackenzie Basin inhabitants respond to this changed climate?

There are a number of Aboriginal communities located within the Mackenzie River Basin particularly in the Northwest Territories portion. In this region, many Aboriginal people pursue traditional land based activities, such as hunting, fishing, and trapping. While to some degree these pursuits are shaped by the availability of western technologies and methods, widespread use of traditional methods and practises continue. The traditional knowledge of Aboriginal people may be generally defined as accumulated knowledge passed down through generations, the result of thousands of years of living in close contact with the land and animals. This knowledge, as pointed out by panellist George Kurszewski, is not static: it forms the basis for Aboriginal peoples' understanding of their surroundings, and the human place in relation to the universe. It develops in accordance with changes that occur over time.[1]

Ted Elliot articulated the link between traditional knowledge and ecosystem science perspectives, which is the holistic approach taken by both. Changes in one part of the ecosystem affects other parts; thus to understand changes, one must consider the whole system, not just the parts. People who rely on the land and water for their livelihoods, such as Aboriginal people, are particularly sensitive to changes. The close relationship of Aboriginal people to the land has resulted in a wealth of information about the complex behaviours of whole ecosystems, and what is necessary to sustain them. It was viewed that this knowledge would be useful to identify system level properties to be studied and evaluated by western science.

Discussion on Question 1

The panel reached general agreement that changes are occurring which correspond with expected results of global warming. Predictions for the future emphasized that global warming impacts would be significant in terms of the balance of the ecosystem itself and what this might mean for the human inhabitants. Most panellists believed there will be significant and negative impacts: loss of habitat, decreased animal and fish populations and changes in land formations and composition. Yet for some species and in some economic sectors, the changes might bring positive effects. For example, Kevin McCormick pointed out that early snowmelts associated with warmer temperatures have a positive influence on goose production at a number of colonies in the Arctic. But then, any positive changes may cause negative impacts as the influence is propagated throughout the system: an increase in goose populations could result in overgrazing of available habitat.

George Low illustrated the potential significance of changes for certain species of fish in the Mackenzie Basin, by describing an event which occurred in 1989:

> We have already experienced warm water related disease problems on the Mackenzie River due to some extreme summer temperatures. In August of 1989, thousands of fish including Longnose sucker and Arctic grayling were killed in Beaver Lake and areas downstream. The kill was attributed to high water temperatures and disease caused by three opportunistic and waterborne pathogens, *Aeromonas hydrophilia, flexibacter, and Pseudomonas putrifaciens.*
>
> The outflow of Great Slave Lake because of its shallow nature skims the warmer water off the surface of the lake. This water is further warmed as it flows through shallow Beaver Lake, the Providence Rapids and Mills Lake downstream. So although the source of the Mackenzie River is a large cold lake, under certain warm and calm conditions it can supply warmer than expected water to the downstream environment.
>
> The 1989 event had a direct effect on the management of fisheries in the region. The catch and possession limits for Arctic grayling were reduced from three daily and five in possession to zero possession during the spawning run (April 1 to May 31) on the Kakisa River, Beaver Lake, and northward to the Mills Lake area. Summer catches were restricted to one daily and one in possession for the sport fishery.[2]

George Kurszewski described changes he has observed in the duration and severity of the seasons over the years. Winter seems to have lengthened and summers have become colder. Spring and fall have all but disappeared. These drastic seasonal transitions may preclude smooth development of plant and animal life cycles.

Ron Graf, drawing on his experience with government mandated wildlife management, illustrated the significance of potential impacts by describing how changes might affect the Bathurst herd of barren ground caribou. Expected changes would impact on population and habitat size, having repercussions for dynamics of natural species interaction. One aspect of these impacts relates directly to calving. At the beginning of May each year the herd heads to its calving grounds east of Bathurst Inlet. Exact-

ly where the caribou calve has been linked with a number of factors; for example, they consistently move far from wolf dens, which are generally located at the treeline. Why wolves den at the treeline is uncertain, but it may be reasonably expected that if the treeline advances about two hundred kilometres, as predicted in a scenario of global warming, wolf dens would likely begin to encroach on the caribou calving grounds. Wolf dens too close to calving grounds would threaten the caribou's ability to calve in safety, increasing stress on the animals, and having possible implications for the herd's population.

Although many observed changes may be attributable to global warming, all respondents raised the issue of uncertainty regarding the causes of change and therefore the significance of global warming impacts: while many changes seemed to correspond with those expected in a scenario of global warming, they might also be caused by other factors. Kevin McCormick elucidated the importance for quantifying impacts from global warming by separating them from natural variations within the system. Quantifying the impacts would have to be preceded by an in-depth understanding of what global warming changes entail; this would lay the groundwork for determining suitable future action.

Discussion on Question 2

Given the uncertainty surrounding possible causes of change, the types of action recommended in response were wide ranging and diverse. Discussion identified possible agents of change: natural cycles and variations in patterns, long range and local contaminant sources, and unexpected natural events. The effects of compounded factors was an issue. How this might be separated from global warming, and also how significant global warming might be in comparison to other individual and combined factors was questioned.

Responses to the second question reflected participants differing mandates, goals, and degrees of control over management decisions, and also reflected the uncertainty about causes and significance of change. Long term and short term strategies were suggested, related not only to ecosystem management, but also to public awareness, bureaucratic and political decision making processes, and individual action. The wealth of suggested actions highlighted the enormous potential for creativity in determining responses; this diversity of suggestions represents a continuum of action. The suggestions fit together into an adaptive management process framework

Adaptive management, which is a process of continual monitoring, reassessment and updated action plans, is a concept which is flexible, adaptive, progressive, changing, responsive, iterative, and anticipatory. Monitoring of ecosystem properties is a fundamental part of adaptive management. To predict the future and develop management strategies accordingly, managers must be able to recognize and understand the changes which are taking place. Where the changes take place, and to what extent changes occur must also be understood. For this, panellists suggested that both western science and traditional knowledge be used. Local people living in close harmony with the land not only have a wealth of knowledge based on collective experience, but as land users, they will likely be the first to see the changes as they occur. This knowledge may be a valuable source of observation upon which scientific studies may be developed.

While a strong emphasis was placed on the need to monitor, panellists also highlighted the necessity for understanding and interpreting the data through ongoing evaluation. Ongoing evaluation was recommended in two areas: in relation to values, and to the state of the environment.

Maurice Boucher stressed the need for ongoing evaluation of values at the personal and societal levels in order to determine appropriate responses to global warming. On both of these levels, definitions of fundamental values affect what choices are made in terms of preventing ecosystem stress and how changes might be met. This also requires re-evaluation of standards, and understanding how individual and societal actions fit with the national and global situations. Values are also determined by the cultural and educational backgrounds of those shaping decisions, and the approaches taken in seeking resolution.

Ongoing evaluation must also be taken in relation to the state of the environment. Maintaining a close watch is not enough; decisions must be made which are related to the value judgments made when interpreting what changes are required to ensure ecosystem sustainability. In this area too, western science must make room for traditional knowledge, particularly when developing management strategies and evaluating resources in areas important to those who depend on the land for their livelihoods. To ensure this integration, in-depth information should be acquired about a wide variety of areas so that wise judgments can be made.

The third aspect of an adaptive management process relates to actions. Panellists suggested a number of possibilities; these are divided into three categories: communication, natural resource management strategies, and political actions.

Communication

One area requiring ongoing effort must be communication among scientists and the public at large, Aboriginal communities, government and decision makers and ecosystem managers. Particular emphasis was placed on the need to obtain a better understanding of each others values. Mutual understanding of one another promotes communication; therefore, Aboriginal communities and scientists in particular must understand each other better. In this way, a common set of expectations about how research is conducted and how it will be used may develop.

Cam McGregor articulated the need for ongoing efforts which facilitate the integration of science and policy. Scientific results must be made accessible to policy and decision makers in a manner which is understandable and relevant. As changes in the land occur, the need for this integration becomes particularly important.

The third aspect of communication relates to the level of public awareness of global warming issues. A concerted effort is required to raise awareness of the issues at the local, national, and international levels. Stakeholders must be made aware of linkages between impacts of global warming in these three spheres in order to make informed and timely decisions. As pointed out by Kevin McCormick, public awareness of potential threats is necessary, since much of the action taken will ultimately be resolved in the political arena.

The fourth aspect of communications identified by several Aboriginal and government panellists is the need for better use of traditional knowledge. In order to make the best use of traditional knowledge resources, responsibility lies with both Aboriginal people and scientists to work together to utilize traditional knowledge. Scientists must seek out existing resources, and Aboriginal communities must assist scientists in gaining access to resources. This relates to knowing each other better; only by establishing solid links between the Aboriginal and scientific communities is there hope for effective collaboration.

Natural Resource Management

Better use of traditional knowledge is not restricted to the area of communications. It is also relevant to the second action category: natural resource management strategies. In this area, the use of co-management bodies, which are resource management bodies with equal representation of Aboriginal and public government representatives, ensures traditional knowledge is incorporated at the decision making level and that it is discussed and incorporated on an equal footing with western science. Again, both Aboriginal and government panellists suggested this as an option. Co-management bodies are in place throughout most of the Northwest Territories; most have been created through the land claims process. Co-management allows stakeholders to articulate their needs at the decision level, and to take responsibility for the resources they use at a management level.

Natural resource management strategies might also be adaptive resource management methods. George Low discussed practical actions: adjusting commercial quotas and catch and possession limits for sports fisheries, in accordance with population numbers, ecosystem health, and managing sustainably. For example, fish populations better suited to changing habitat may emerge naturally and be encouraged through management. The nature of change would demand flexibility, with some adaptive strategies being implemented gradually, while others may require immediate responses to critically changing situations.

Maurice Boucher questioned whether observed changes are in fact due to global warming. He used Fort Resolution's observation about contaminants found in the water and fish as an example of factors contributing to changes which potentially weaken the ability of the ecosystem to respond effectively to climate change. In combination, a series of factors might create a situation where despite best efforts at management, ecosystem sustainability might be difficult to maintain. Several panellists echoed the need for communities to work towards prevention, or towards developing mitigation strategies to improve chances that the effects of global warming would not be intensified by other factors.

Political Actions

The third category of suggested actions falls into the political sphere; these actions were suggested by Aboriginal panellists and relate to the necessity for meaningful involvement of stakeholders in the resource management process. Settlement of Aboriginal land claims is fundamental to ensuring that Aboriginal communities participate fully in promoting ecosystem sustainability. Aboriginal peoples have a vested interest in maintaining sustainable ecosystems, since as cultures their traditional way of life is dependent upon wise stewardship of the land and resources. Elder Charlie Snowshoe emphasized that, for the Gwich'in people, settlement of land claims mean that Aboriginal land users control resource use and regulation. Since they are dependent upon the land for their own cultural and physical survival, they are dedicated to protecting it.

George Kurszewski expressed the need for widespread support for self government processes to ensure local control and involvement in resource management and the development of resource management strategies. Self determination, for many Aboriginal communities, is a fundamental prerequisite for attaining effective local involvement in ecosystem management, and the establishment of processes incorporating Aboriginal people's traditional knowledge and equal participation in sustainable ecosystem management. Self determination must become a reality for Aboriginal communities; this is the key to establishing a solid foundation for the development of a full range of resources necessary to take part in planning for the future and adapting to change.

Questions from the Audience

Ian Burton from Environment Canada raised the possibility that actual rates of climate change might outpace expected rates, and asked about implications for adaptive action on the part of stakeholders. His question was two fold: Should we be preparing for more rapid change than models have led us to believe, and are there things we might do to prepare for possible rapid changes? Ron Graf responded by noting that large scale monitoring systems, such as the International Tundra Experiment (ITEX) and the Ecological Monitoring Assessment Network (EMAN), assist in anticipating change. At the local level, population cycles of animals such as hare and lynx also serve as indicators of change. We should also pay more attention to calving grounds, and changes in fire (we may have to fight tundra fires?). George Kurszewski added that Aboriginals engage in continuous activity on the land, and scientists should make better use of this human resource that is already there, but Aboriginal people need to be asked. Traditional knowledge is an underused tool.

Fred Wright from the Geological Survey of Canada then asked if Aboriginal groups might establish a standardized monitoring system, utilizing resource users active in the region. Maurice Boucher responded that at the present time, resource users, and people living on the land serve as an informal monitoring system. Information about irregularities and changes in the animals, land, water, and fish is communicated to the Wildlife Harvester's Committee in Fort Resolution, which has primary responsibility for these types of issues. This kind of informal information sharing is a convention throughout the north.

Don Antoine, a representative of the Deh Cho First Nations, spoke about the necessity for the development of a cooperative management plan within regions to promote sustainable harvests. Such initiatives must include individuals, Aboriginal organizations, government, and industry. Sustainable resource management has always been the cornerstone of Aboriginal resource use, and traditional knowledge can serve as an important source of information about how to maintain sustainable ecosystems in a scenario of climate change.

During the discussion, panellists commented that while many changes are occurring in the north, it is uncertain which were signalling climate change, and which were signalling other environmental problems.

In response to a question by Barbara Nicholson, Central Connecticut State University, who sought clarification about what action northerners should take to address global warming, Charlie Snowshoe uncovered a fundamental element for responding to global change: the situation is that like many of the other issues northerners are grappling with, solving global warming problems involves a learning process for everyone. Maurice Boucher responded by recognizing that communities must take action at the local level to address issues. More awareness of the individual's impact on the environment is needed, and could be achieved through initiatives such as recycling programs.

Notes

1. Legat, Allice (ed) *Report of the Traditional Knowledge Working Group,* Yellowknife: Department of Culture and Communications, Government of the Northwest Territories, 1991, p.10- 11

2. Low, George, *Speaking Notes: Theoretical Effects of Global Warming on the Management of Freshwater and Andromous Fish,* May 7 1996.

Stewart Cohen introduces the Round Table discussion on sustainability of ecosystems. From left to right the panellists are: George Low, George Kurszewski, Ted Elliot of Colorado State University, Charlie Snowshoe, Cam McGregor, Kevin McCormick and Ron Graf. Maurice Boucher is hidden behind Dr.Cohen. (Photo by I. Hartley)

Round Table #3: Economic Development

Rapporteur: Randall Barrett

Alberta Environmental Protection, Edmonton AB

Chair: Rodney White, Institute for Environmental Studies, University of Toronto, Toronto ON
Joe Ahmad, GNWT Energy Mines and Petroleum Resources, Yellowknife NT
Chris Fletcher , B.C. Ministry of Forests, Victoria BC
Charlie Furlong, Mayor of Aklavik, Aklavik NT
Daryll Hebert, Alberta Pacific Forest Industries, Inc., Boyle AB
Bridgette Larocque, Metis Economic Development Corporation, Metis Nation, Inuvik NT

Rapporteur's Observations:

Future economic development in the Mackenzie Basin is going to be a new ball game with old rules. All panel participants commented on the Mackenzie Basin Impacts Study (MBIS) posters and their talks focused on what implications the research meant to them, their businesses, and their community. Several panelists underlined that the northern economy will continue to be driven by the old rules of supply and demand. Traditional native knowledge and movement to ecologically based management systems, however, may temper the affects of supply and demand in the future. The changing political landscape of the area, due to recent and pending land claim settlements, will mean economic development decisions and environmental management strategies will now include native governments and interests as full partners. It will be a new ball game for scientists as well. Scientists will need to build more two-way dialogue with local communities into their research to better incorporate local knowledge, decision making processes, and values. Research workplans should include a commitment to: communication, uncertainty analysis, and relevance to local and regional planning issues.

Rapporteur Notes

Daryll Hebert, Alberta Pacific Forest Industries, Inc.

Daryll Hebert discussed his work in developing an ecologically based forest management program for Alberta-Pacific. He began his presentation with a short anecdote about a trip he had recently made to Mexico City. He was struck by the large number if vehicles and poor air quality there compared to Vancouver. He made the point that the improvements in vehicle emissions made in B.C., favoured by the Honourable Moe Sihota, would not affect the global concentrations of green house gases. This underlined the connection between human population growth, high standards of living, food sources and growth in greenhouse gas emissions. Economic rules of supply and demand dictate how resources are being consumed. Demand by human population growth is a prime factor driving the growth rate of greenhouse gases, and may be pushing humanity up to the limits of the carrying capacity of the Earth.

His work designing the sustainable forest management system for Alberta-Pacific Forest Industries did not consider global warming because the information on impacts was not readily available at the time. Immediate priorities for design included roads, harvest planning, annual allowable cuts, public task forces, and traditional land use studies. These immediate requirements needed to be integrated with some long term planning. Emerging research on impacts of a changing climate is the least definitive set of information, thus the billion-dollar industry is still making decisions on old ideas, old information, and increasing demand.

As for the question of how the results of MBIS affect his vision of the future, he felt in the short term they may be added as another element in modelling work for long term planning at Alberta-Pacific Forest Industries and may even be incorporated into his work in the national centre of excellence in sustainable forest management at the University of Alberta. Daryll Hebert cautioned that even long term decisions at pulp mills are still driven by supply/demand economics. Despite the sustainability of the silviculture practices, the price-per-product output still has the strongest say in planning decisions.

In closing, Daryll Hebert reflected on the years of work involved in developing the ecosystem based sustainable forest management system. One of many challenges of planning for the future include trying to get an estimate of 'natural variability'. He reflected that longer baselines for forest climatology are required before a better definition of natural variability could be established.

Joe Ahmad, GNWT Energy Mines and Petroleum Resources

Joe Ahmad started with an observation that economic forecasts over the past twenty or thirty years had often been off base. Combining economic and climate forecasts leaves wide margins of scientific uncertainty on specific economic development forecasts. Economic development and prediction of weather or global warming are best expressed as probabilities. From an energy perspective, Mr. Ahmad spoke of ways the NWT can reduce the probability of global warming. The Northwest Territories spends about 100 million dollars a year on energy. Ninety percent of that money is spent on refined petroleum products. Since petroleum products release greenhouse gases when they are burned, there are three key things the Northwest Territories can do to reduce contributing to climate change: (a) reduce energy consumption (b) supply more renewable energy (c) reconsider valuation of energy.

Reducing energy consumption can be achieved by energy conservation and energy efficiency.

Supplying more renewable energy, such as wind and solar power, means looking at the economic viability of renewable power often on a community by community basis. Wind power is viable in a number of northern communities, but the price of renewable energy needs to be more competitive with petroleum products. Most communities are still not prepared to pay more for renewable energy. Even though the NWT produces modest greenhouse gas emissions, they can set an example for the world through more use of renewable energy.

The calculated cost of energy could be re-evaluated to include not only the capital and labour inputs, but also the social costs of fuels. The MBIS work on the impacts of global warming may help in calculating the social cost to communities of burning fossil fuels. This newer valuation of fuels however, will require a remarkable change in the thinking patterns of people and even in our collective value system.

Bridgette Larocque, Metis Nation

Bridgette Larocque felt the MBIS work shows climate change could affect the future of economic development patterns which will affect resource management policies and planning. Although the scientific information on the impacts of climate change is important to her, it is more important that the traditional Metis knowledge be respected and used in developing management plans for the region. Involvement of Metis in consultation and setting up of future economic development will be key in developing plans to address climate change. Metis economic development system is inclusive of hunters, trappers, traders, and entrepreneurs. It is a system that respects the environment and people that exist on the land.

Climate change impacts on the Mackenzie Basin will affect the Metis existence and definitely the environment. Metis have travelled until they found an area compatible to their traditional lifestyle and needs. They have adapted and will continue to adapt to change. One of the most important adaptations for the future will be for a patient, two-way exchange of information between scientists and Metis. A phone call is not enough. In this way, traditional knowledge and scientific information will both be used in formulating economic strategies to protect both the environment and Metis homeland.

Chris Fletcher, B.C. Ministry of Forests

Chris Fletcher, a timber supply analyst from the British Columbia Ministry of Forests, introduced the notion that due to the wide number of pressing issues facing the forestry industry, climate change impacts had not been significantly factored into the decision process. Immediate policy issues facing B.C. forestry presently include: regional and sub-regional land-use planning, the protected area strategy - to increase protected areas of the province to 12%, a new forest practice code, uncertain timber supply inventories and projections. Biological uncertainties include biodiversity and ecosystem management, pest and fire disturbances, and growth to yield relationships. More complications are added by considering timer supply, the United States trade negotiations and the social value British Columbians place on forests now and into the future. Given all of these planning issues, why is climate change any more important to address now?

Chris commented on how much he had learned about climate change by reading the scientific posters displayed around the room. He felt that research now needs to build process models that will incorporate uncertainty and newly emerging knowledge into decisions. The status quo is flexible enough to handle existing uncertainties inherent in the forestry industry and achieve management objectives of the forestry program. Management objectives are set through public consultations and field decisions, based on modelling and best available information, are geared to deliver the objectives. The amount, spatial and temporal features of climate change impacts are so uncertain that it is difficult to make a case for doing more than the status quo. The precautionary approach or 'no regrets actions' (initiatives that reduce green house gas emissions but make

sense in their own right) are the status quo's reaction to the uncertainty.

Models are representations of our understanding of a system but they do not generate hard answers. He interprets model results that say "this is the impact" with great caution because models are best used to show uncertainties, highlight research priorities and show conceptual holes in our understanding of the system. Computer models, or conceptual decision process models, are both driven by the values of the underlying system. If the system values increased economic output or traditional knowledge solutions, then the models will sketch out those outcomes. Perhaps through a better understanding of social, economic and physical values, our society's models will evolve toward a more balanced and sustainable future.

Charlie Furlong, Mayor of Aklavik

Charlie Furlong is mayor of Aklavik, a small community in the Mackenzie Delta. Aklavik floods every ten years or so and the community was the subject of an MBIS research project. He appreciated the scientific research that had taken place in his community and the consultation that should take place following it. He reflected that scientific research was entering a new era. Partnerships with local people, before and after research, would be a key component of any future work.

MBIS research highlighted impacts on ice roads, permafrost, animal populations and distribution. Charlie Furlong commented that climate change could affect land use and that longer summers would also bring more insects to the area. If impacts occurred on short time scales, they would hurt his town and his community's lifestyle - especially those who do trapping. If changes would appear over fifty or one hundred years, they would be easier to adapt to. As a small business operator in Aklavik, he had little time to spend on environmental management and so the MBIS work would likely not factor into his every day operations.

In the short term, he felt the land use policy decisions in his area would be strongly influenced by land claims settlements. In Aklavik, for example, the Gwich'in are now major land owners and before future economic development, or research on it's impacts can occur, the Gwich'in would demand full consultations. New community level partnerships of traditional knowledge and scientific research would be key in directing future development in his area. Long term monitoring would be needed to see if problems arise. To make the MBIS research relevant to his community's planning, plain language interpretations would be necessary. Regional partnerships should be built, with equal access to information.

Questions

Louise Comeau, of the Sierra Club, expressed concern with the panel's tone of powerlessness. She noted that Moe Sihota's position on vehicle emissions standards may help stop efforts to erode vehicle emission standards in the United States and California . Renewable energy advancements, such as wind energy technology, can be used in the NWT and exported internationally. She urged the panel to move beyond victimization and act locally to ensure global commitments are upheld.

> **D. Hebert:** He agreed with Louise, and clarified that he would support Moe Sihota's work to reduce emissions in B.C. if he was more certain it would result in reduced emissions in developing countries like Mexico. He noted that Alberta-Pacific is presently working with energy companies on projects to sequester carbon dioxide in forests and improve the carbon balance of areas managed by his company.

> **J. Ahmad:** He agreed with Louise, and clarified that the NWT can make a significant contribution to reducing emissions through renewable energy as a model for the world to follow. It also empowers communities to make positive contributions to a global issue with local actions.

Francis Widdowson, NWT RR, expressed frustration with the panel because they were going around the sustainability of the economy. The Earth has finite carrying capacity, so discussions about adapting to impacts of climate should include discussion of sustainability of economic growth. Sustainability is a shared goal. Is our present economic system sustainable - given that growth cannot continue indefinitely without competition for finite resources causing conflicts?

> **D. Hebert:** He agreed with Francis, that the global ecological implications of unsustainable growth are over riding. He cautioned that production levels, based on supply and demand, are still the prime indicators of economic success. It will be a challenge to change and incorporate ecology into the management structure of economists, engineers and foresters.

Jim Bruce, representing the Canadian Climate Program Board, noted that over the past 70 years the boreal forest has turned from a sink to source of greenhouse gas

emissions. The amount of forest consumed by fires has increased over the same period and according to the MBIS is likely to increase under a scenario of doubling carbon dioxide. Why are foresters not interested in climate change?

C. Fletcher: Foresters' plates are filled with other priorities and competing issues. Local stakeholders are also not showing a concern for climate change, and since public priorities lead the government agenda climate change has still not been factored in. It should be, but it is not.

D. Hebert: The invasion of people and resource exploration in the boreal forests over this period along with the stresses of pine beetles and tent caterpillars affects disturbances of the boreal forests. The cause and effects of climate change were still unclear in the boreal forest. He had examined Mike Apps' forest fire data and even Mike Apps would agree there is still no clear signal of climate change.

Dale Rothman, Environment Canada at University of British Columbia, felt uncertainty analysis for allowable cuts in B.C. should include consideration of climate change impacts. Mike Brklacich, Carleton University, observed that uncertainty is incorporated into many resource decisions. Why is climate change any different?

C. Furlong: Climate Change is still low on the priorities compared with other stresses on the environment like logging, mining, and oil and gas exploration. If more partnerships are built between scientists and local native groups, long term climate change impacts could be built into land planning to address these issues.

D. Hebert and **C. Fletcher:** both suggested that they would now try to incorporate climate change as a factor in the computer models used to analyze for allowable forest harvests.

Laszlo Pinter, International Institute for Sustainable Development, noted that the difficulty of framing the problem of climate change in economic decision making could be addressed by designing indicators for sustainable development. Indicators could incorporate biophysical factors into them and be used in the valuation of benefits/costs for economic decisions.

Wrap-up Points

C. Furlong: The future will include land claims. Native Elders are concerned about the environment, but will need to build partnerships to encompass traditional knowledge and values in economic decisions

C. Fletcher: Future research should include developing a systematic process to incorporate uncertainty in decisions. Opportunity exists to incorporate climate change impacts into planning discussions underway in British Columbia.

B. Larocque: Metis will review MBIS documents and how they impact on sustainability and economic development for the Mackenzie Basin. Metis are not fearful of change and they have processes to establish a strategy to protect all Metis land.

J. Ahmad: The NWT will focus on proactive work to increase benefits and reduce risk to the region from the climate change issue. Climate change is still not high on the community level agenda.

D. Hebert: Do whatever you can locally to trigger global improvements. Society needs to get beyond a demand driven economy. Bio-monitoring is important to make sure we are getting where we want to go ecologically.

Members of Round Table on Economic Development (left to right): D. Hebert, J. Ahmad, B. Larocque, R. White (Chair), C. Fletcher, C. Furlong. Photo by I. Hartley, May 7, 1996.

Round Table #4: Maintenance of Infrastructure

Rapporteur: Terry Zdan

Alberta Environmental Protection

Chair: Dr. Rod Dobell, Winspear Professor of Public Policy, School of Public Administration, University of Victoria.
Pietro de Bastiani, GWNT Transportation, Yellowknife.
Randy Cleveland, Assistant Deputy Minister, GNWT Public Works & Services, Yellowknife.
Alan Hanna, AGRA Earth & Environmental Limited, Calgary.

The panellists' comments were presented in the context of several decades of collective experience of planning, designing, building and maintaining transportation routes and building structures in permafrost areas within the Mackenzie River Basin. Evidence of climate warming is being experienced and is presenting challenges to maintaining existing infrastructure and design and construction of planned development. Environmental, economic and social considerations need to be addressed in the management of infrastructure in the north. A poster panel on risk assessment may provide guidance for future direction and action.

Chair's Introductory Comments

Dr. Dobell commented that not only climate change, but ecological processes, social institutions, and human responses and adaptation are all in a state of flux. He suggested the concept of infrastructure can be expanded from transportation, communication, waste disposal and built environment to include emergency response systems, insurance mechanisms, monitoring and regulatory systems, education, health and social support systems. More generally infrastructure can include social and cultural institutions that pool risks and support people in times of stress and change, or govern harvesting and land use activities in a sustainable manner.

Dr. Dobell gave encouragement for human behaviour to respond to the challenges to reduce emissions and pressures on the biosphere. He suggested possible responses to climate change might include changing design and construction standards, species conversion in forestry, fisheries or wildlife, and regulatory reforms governing land use and activity siting.

Dr. Dobell asked the panelists the following: "a) having considered the MBIS study, how do you read all this evidence and these signals as to the future, and is that future acceptable and manageable?" and, "b) given your appraisal of the seriousness of the risks identified, what do you see as feasible and appropriate responses to these features of the outlook for the basin?"

Pietro de Bastani, GWNT Transportation, Yellowknife.

Marine, rail and road transportation infrastructure were described. Currently, there is a narrow window for shipping in the Beaufort. In Cambridge Bay, mobile ice is a barrier to shipping and warming may result in increasing tonnage of ice breakers, and has obvious implications for shipping in the Arctic. The Mackenzie River is very important for tug and barge transportation, especially fuel, to the north, and is dependant on high water conditions. Federal dredging programs are being culled back and potential for lower stream flows will result in higher transportation costs.

Rail transportation will be impacted by the stability of permafrost in the taiga and tundra ecozones.

The north relies on non-traditional winter road systems. Constructing winter roads depends on the amount of snowfall and the time of freeze up. Shoreline approaches require particular attention to mitigate environmental impacts and be structurally sound to support truck traffic. In summer months, a system of roads and ferries are used. This infrastructure is experiencing erosion from permafrost melting. Changes in rates of run off and melting affect water flows. This will result in revising and setting dates for cut-offs and closures of roads. The future development of new roads, to new mines etc., will need to be carefully assessed.

Air transport is reliant on ice strips for landing to service communities. They are currently experiencing erosion problems in areas impacted by fire.

Randy Cleveland, Assistant Deputy Minister, GNWT Public Works & Services, Yellowknife.

Annual capital construction costs in the NWT range between $80 to $100 million, plus $200 million operation costs. Public buildings include water works, hospitals, arenas, and correctional institutions. The north depends on the cold and deals with the cold.

Construction techniques are sensitive to changes in ground temperature, but a changing rate of warming sur-

face temperatures will necessitate adaptation of new techniques.

Important considerations for siting buildings include water level changes and flushing action, slope stability and coastal erosion. As long as these are slow processes we can adapt. But these are not just engineering questions. Adaptation is connected to lifestyles, and cultures. New technologies and construction usually mean imported materials, higher costs and imported labour. The ecological footprint from construction in the north is very large and "sustainable construction" compatible with aboriginal lifestyles in the north needs to be considered.

Technology will change, but it won't mitigate the problem of global warming. Appropriate building technology will develop, and demonstration projects should be advocated. The GNWT has done little proactive work but is now looking at sustainable construction.

Dr. Dobell: Commented that both presenters suggest current infrastructure can cope with climate change if change is gradual but what about lifestyle adjustment to sustainable construction to reduce the North's ecological footprint?

Alan Hanna, AGRA Earth & Environmental Limited, Calgary.

Alan Hanna participated on the panel as an engineer with work experience on pipelines in the north and in Russia and not as a representative of InterProvincial Pipelines Limited (IPL).

In the context of geological time scales the rate of temperature change may be accelerating. In the short term this is not significant, but in the long term we have to be concerned. Generally construction in the north that is sited on bed rock is not a concern. Fine grained, ice-rich areas are thaw sensitive. Discontinuous permafrost zones would be expected to show low to high impacts, and, in continuous zones, low impact from climate change.

Design approach standards consider temperature conditions and slope stability. Fires may result in mud flows and impacting infrastructures. Dams and dikes may need to be monitored and retrofitted with insulation or artificial ground cooling. Large pipelines may need to be chilled to reduce their impact on right of ways.

Generally there is a robust engineering knowledge of how to deal with warm and cold permafrost. We know how to deal with this and will be watching for shifts in locations of permafrost melting.

Dr. Dobell: Commented that other risks, such as fire and storm surges, were not addressed.

Questions

Kevin Jardine, Greenpeace: Kevin cautioned that the temperature change may be considerably greater than 2 - 3 degrees and whether or not panellists might be concerned about pipeline ruptures and other impacts. Alan Hanna responded that temperature swings are variable and we should not become alarmist about the situation. He suggested the tool box is there. We will have to adapt, but not over-react. It would be less expensive to remedy the situation rather than to invest in large capital expenditures now.

Maurice Boucher, Fort Resolution Environmental Working Committee: Has consideration been given to incorporating alternative energy systems in the design and construction of northern buildings? The use of waste heat and wind energy is being looked at. There is some utilization of passive solar technology, except not in government buildings, and implementing energy conservation programs. Seismic activity zones are also being examined (?)

David Grimes, Environment Canada: Commented that the science tells us the rate of climate change in the Mackenzie Basin will be greater than that of the past 100 years. Design standards are driven by past experience and climate change introduces a new complexity. What research and monitoring is being done to address this? Pietro di Bastiani replied that existing information from Radarsat on sea ice is not used because of downsizing and closing of functions. Some buildings are deteriorating while we face budget reductions.

Francis Widdowson, GNWT Renewable Resources: What are the implications of climate change in a world we use differently than we did 1000 years ago, and how would the north be affected by linkages to the world economy and outsourcing material, labour etc. ? We want more all weather roads, air and marine transportation that will cost money. It was agreed this will increase the north's ecological footprint.

Joey Stewart, University of Texas-Austin: We now have a lot of information about how the north will be affected by climate change. How much will this cost? Remedial work to fix existing infrastructure

may be required and will be expensive. Developing new transportation systems will also be more costly than in the past. There may be new ecotaxes (emission charges?) that will add to the cost of doing business.

Terry Zdan, Alberta Environmental Protection: You've all talked about current conditions, new information, changes, ecological footprints, management responses, economics. Have you considered the opportunity to systematically address sustainable development in the north by approaching the infrastructure issue through an information system to collect and analyse data and set management targets by adopting a State of Environment Reporting framework to track stress, condition and response indicators. Information exchanges between all parties is encouraged as well as information dissemination, proscribing policy futures, codes of practice and monitoring.

Roundtable Session #5: Impact of Climate Change on the Sustainability of Native Lifestyles in the Mackenzie River Basin

Rapporteur: Laszlo Pinter

International Institute for Sustainable Development

Chair: Whit Fraser, Canadian Polar Commission, Ottawa
Joanne Barnaby, Dene Cultural Institute, Hay River
Lou Comin, Wood Buffalo National Park, Fort Smith
Don Antoine, Denendeh Environmental Committee, Fort Simpson
Herbert Felix, Inuvialuit Game Council, Inuvik

The subject for this discussion was the impact of global climate change on the sustainability of native lifestyles without proactive action.

Roundtable members in the first part of the session were asked to respond to the following question: given the climate change impacts scenario described by the Mackenzie Basin Impact Study (MBIS) and related projects, what is your view of the region's future, assuming the region does not respond proactively to climate change?

During the thousands of years since native people have been living in the Mackenzie river basin they have learned to successfully adapt to changes in environmental conditions. Changes during the last decades have started to occur at a faster pace, nomadic people settled, young people gained more and more education. As Joanne Barnaby pointed out, the impact of a changing climate is an addition to a long list of factors that is expected to affect the livelihood of people in the North. There are not only environmental pressures on traditional livelihoods, but also social and economic ones. The traditional way of life has been dependent largely on the harvest of renewable natural resources and therefore changes that influence this resource base will directly affect people's livelihood prospects. At the same time, it is also recognized that an increasing number of native people seek their livelihoods in the wage versus the subsistence economy and this factor together with the import of goods from the outside world may decrease their reliance on the local resource base. With or without climate change, native lifestyles are in flux and the specific impact of a changing climate needs to be considered in this context.

People living off the land are usually the first to notice any change. In the past years numerous phenomena have been observed that could be related to among other factors with a warming regional climate. The symptoms we see today can be a basis for assessing the impact of an more significant climate change on native lifestyle and livelihood in the future.

Impact of seasonal change

The perception of local residents is that there has been a slight, but noticeable shift in the length and transition between seasons. Dan Antoine mentioned that freeze-up occurs later and ice breakup occurs sooner than in the past. Perhaps as a consequence of thinner ice than usual and a more gradual transition between seasons, ice breakup is less forceful than in the past when violent breakups were frequent.

Impact of changing water levels

Water levels across the Mackenzie Basin are at an all time low, possibly as a result of less precipitation and higher evaporative loss. While on the sub-regional level the impact of human development, such as the Bennett dam can be very significant, overall the cause of water deficiency is believed to be climate related. Water is essential for the entire regional ecosystem, including wildlife and vegetation, but some species are especially dependent upon the availability of water. The impact on wildlife species that have significant value for the regional economy and the livelihood of people, will have direct influence on native lifestyles. For instance, the disappearance of muskrat from the Peace-Athabasca delta, as mentioned by Whit Fraser, is related to decreased water availability. Trapping was a major industry a few decades ago, but according to local people there are no muskrats in the area any more, therefore, people need to look for alternative sources of income, one of which may be finding a job in the wage economy.

Impact of flooding in coastal areas

While water shortage is a problem on the land, coastal communities are expected to be at risk of flooding if a projected sea level rise occurs. In particular, Tuktoyaktuk and Inuvik would be affected. Given sufficient warning

and time to change, communities would be able to relocate. However, the cost of community relocation would be beyond the communities' economic capability.

Impact of increased forest fire frequency and intensity

Forest fire with moderation was considered a natural and beneficial force in native culture, replenishing and rejuvenating the forest. Increased fire frequency and intensity, however, can bring about more extensive habitat change that will potentially affect species composition. As Lou Comin mentioned, some species such as the martin, fisher or squirrel require mature forests. Other economically important species, such as the caribou may be also affected. The larger burns would mean a decreased availability of this type of habitat and therefore decrease population densities of species some of which are important for the trapping and hunting industry.

Wildlife impact

Most climate impacts that affect water resources and vegetation, such as increased risk of fire, are expected to have a cumulative impact on wildlife including terrestrial and aquatic species as well as birds. The impact is expected to be species specific and there is high uncertainty with respect to the adaptability of particular species to the changes that will occur.

Wildlife is the most important harvested resource for native people because of hunting, fishing and trapping. It is critically important in the economic sense, primarily as a source of food, income and traditional clothing, but inseparable from the cultural importance for maintaining traditional systems of knowledge and identity. Changing impacts on wildlife will require that native communities adapt by modifying traditional activities, such as trapping, fishing, and hunting patterns. Although successful adaptation has always been part of their life in the past (e.g., adaptation to the population cycles of caribou), the predictability of the extent, duration and speed of changes made adaptation possible. There is a real concern that if changes affecting wildlife are fast and dramatic native communities would be left in a very vulnerable position. Some of the economically important wildlife species that would be sensitive to climate change include caribou and muskrat.

Impact on employment opportunities

Climate change impact on employment opportunities in the region is expected to be mixed. The employment picture has significantly changed in the past decades and continues to change today due to several reasons. As Herbert Felix mentioned, children are better educated than their parents and grandparents. There is improved access to local communities, and in some cases there is regular air service that people use to commute to their jobs. The decision to take up a job in the wage economy instead of trying to make a living off the land, may be linked to the success of resource harvest. If muskrat or caribou has disappeared from an area, people are likely to look for alternatives and if employment in the wage economy is a possibility, they may choose that option. All this could and does mean a loss of traditional lifestyle, an essential part of which is using resources the land and water can provide. While climate change impacts on traditional activities are uncertain, largely because of the uncertainty of how wildlife will be affected, there are some areas where new employment opportunities in the wage economy may emerge. These may include more jobs in firefighting due to an extended firefighting season, or more jobs in tourism.

Responses to the climate change impact scenario

In the second part of the session, roundtable members were asked to reflect on the question, "what responses to the impacts scenario, as discussed in the first part, should be considered by the regional community"?

The roundtable discussed different strategies to respond to climate change impacts. Included are measures to improve our knowledge regarding the actual occurrence, severity, and impacts of anthropogenic climate change. Emphasis was also given to strategies aimed at decreasing greenhouse gas emissions and strategies to increase the success of adaptation if more serious climate change occurs.

The need for more effective partnership-building between government and native communities is a critical cross-cutting issue and was brought up in several contexts in the session. One of the most important areas of collaboration should occur in the area of integrating western science with the traditional knowledge of native people. As Dan Antoine put it, "we have to start working together more often, we have to sit together on one common ground, because it [climate change] is affecting everybody and every living thing, every living creature that's around us". There is a need to document traditional knowledge as it is done for instance at the Aurora Research Institute in Inuvik where traditional knowledge is put on a GIS platform. But there is even more need for incorporating traditional knowledge

into ongoing and planned activities on the land. In other words, collection of information should not be seen as the end of the process, instead the knowledge and information collected should be put to use in modern management practices as well as traditional activities. For science and resource management it means more attention being paid to understanding traditional knowledge, for government it means involving native people early on in decision-making processes, and for native communities it means more interaction between elders and young people and most importantly an understanding and respect for the traditional lifestyle.

Collection of baseline information

Collection of baseline information on wildlife, water, vegetation, landforms, weather, harvest rates, social conditions, employment, and many other factors is essential in order to establish a baseline so we know if change takes place. Through baselines we can identify the pace, direction and impacts of change on other resources. As Herbert Felix mentioned, this information is necessary so we know what resources and values are at risk and need protection, and what is the time frame of changes. Collection of baseline information on water quality and quantity, wildlife species, climatic trends and events, and many other factors should be an ongoing effort so changes over time can be detected. Monitoring should be a collaborative effort, relying on scientific methods and instruments, but also depending on the information and knowledge of people on the land. Traditional aboriginal knowledge is based on the experience of many generations and has a long term historical perspective that is not the case with management methods that are based on modern science. As both Joanne Barnaby and Dan Antoine confirmed, native people and elders are more than willing to share this knowledge. In terms of monitoring they are the ones on the land the most to see changes first, and they are the most affected by these changes. They think that it would be wise and necessary to use the information they have to understand change - whether due to climatic or other factors - on the land.

Eliminating anthropogenic causes of climate change

People in the north also need to take responsibility for their fair share in eliminating anthropogenic causes of global warming in their own activities. As Lou Comin pointed out, without preventive action the situation can expected to increasingly worsen. Preventive action should involve awareness raising through educating local people and building on their creativity and ability to adapt. Results of the study should also be used to influence industry and government at appropriate fora to decrease the pressure that is contributing to climate change, showing the existing and potential costs and effects of climate change for the land and people in the North.

Facilitating local adaptation

It is recognized that even if immediate preventive action is taken, the impact of climate change is expected to increase in the foreseeable future, requiring adaptation to changes in wildlife cycles, weather patterns, seasonal shifts and so on. Successful adaptation on the local level will require programs involving local people and more involvement from the general community in order to develop an ownership of solutions. Local people need to understand and be part of developing strategies that will make a difference on the ground otherwise there is a danger of frustration and consultation burnout. Dan Antoine mentioned the Community Resource Management Projects (CRMP) as an example for working out solutions with hunters and trappers in an integrated management framework on the community level. Sharing information and gaining more understanding of traditional activities should be an essential component of projects. Adaptation may require serious constraint by local people. For example, the community may have to make a decision against commercialization of wild game if the commercial harvest would deplete populations of increasingly vulnerable species beyond their carrying capacity.

Training programs

Beyond traditional knowledge, adaptation to climate change will require training programs in order to have people with leadership and management skills in areas of highest importance. Dan Antoine mentioned that the creation of the Territory of Nunavut in 1999 will require well-trained people, but today there are very few of them. More training programs, like the one for aboriginal youth on renewable resource management at the Aurora Research Institute in Inuvik, may be necessary to prepare them for the tasks ahead.

Communicating research results

Results of scientific research should be made accessible to the broader population in the region as one of the preconditions for more involvement and partnership building. It was emphasized that a plain language version of Mackenzie Basin Impact Study results should be prepared

and made widely available to communities in the region.

Cost of responding to climate change

Responding to climate change impacts may be a potentially costly exercise, especially if the impact on the North turns out to be proportionately more serious than elsewhere in the South. Resources should be strategically allocated to both preventive measures and developing adaptive capacities to climate change.

Conclusions

Native communities in the Mackenzie Basin have been undergoing cycles of changes and adaptation for many centuries. Given sufficient time, native communities in the past found ways to accommodate and successfully adapt to gradually evolving conditions. However, the pace of changes in the last decades have accelerated and climate change is adding an additional layer of complexity to this already complex picture. Impacts are cumulative, and there is a great deal of uncertainty concerning the responsibility of climate change for symptoms seen on the ground. Nevertheless, the session has clearly identified pathways through which climate change may affect resources native communities rely on and therefore the lifestyles of native communities themselves.

Changes in the climate and the natural ecosystem parallel socio-political developments, such as the 1999 creation of Nunavut, a new jurisdiction with its own institutions and system of governance. Dealing effectively with the challenges of climate change will require a collaborative effort between the new institutions, local communities, federal agencies and international organizations. Central to these efforts will be the protection of land and its resources that are the basis of traditional lifestyles in the Mackenzie Basin.

All photos by I. Hartley, May 7, 1996.

Round Table #6: Recommendations

Rapporteur: Pamela Kertland

Environment Canada, North York ON

Chair: Stewart Cohen, Environment Canada at University of British Columbia, Vancouver BC
Joe Benoit, Gwich'in Land Administration, Inuvik NT
Jim Bruce, Canadian Global Change Program and Canadian Climate Program Board, Ottawa ON
David Malcolm, Aurora Research Institute, Inuvik NT
Rodney White, University of Toronto, Toronto ON

Stewart Cohen (chair) opened the session by giving a brief review of the highlights of the MBIS project, which he has directed since its inception in 1990. Noting as successful the goal of understanding the impacts of climate change on the area, he also cited the development of new scientific information and techniques, the new network of researchers and stakeholders, and the new relationship between northern residents and southern scientists as other benefits of the project. Dr. Cohen challenged panel members and the audience to make specific recommendations on how this kind of research could be better done and what the next steps should be.

The panelists each made a short presentation after which the proceedings were opened for comments from the audience. The key points made by the panelists and audience are summarized under the following headings: communication, monitoring and traditional knowledge, research and collaboration, and other individual points.

Communication

It was pointed out that good neighbours communicate and thus a plan for communication, from local to global scale, should be built into MBIS and any similar research program. The need for communicating in "plain language", ensuring that all can understand the results, was pointed out. Information that is not clearly understandable will be ignored and thus will result in a lack of action or concern. Scientists were also encouraged to speak out strongly, limiting their use of the terms "may" and "could". This view arose from the fact that many decisions made by policy makers are not based on "100% certainty" in other fields and thus scientists not be held hostage to the ideal of absolute certainty. The messages from this meeting should aim to "make decision-makers decide to make decisions now".

It was suggested that use be made of organizations such as the Canadian Climate Program, Canadian Global Change Program and the Canadian Polar Commission and that they be asked for help in disseminating messages and using the information as part of their lobbying efforts. Organizers were asked to ensure that the messages speak to all Basin residents, aboriginal and non-aboriginal from both north and south of "60". All meeting participants were encouraged to help in this endeavour. It was pointed out that pictures can have a strong impact on people and this mode of communication must also be considered.

Monitoring and Traditional Knowledge

A key suggestion on this topic was the request for the creation of a "Mackenzie Basin Monitoring System" which would include both empirical and traditional knowledge based observations. It was noted that many important data were collected over the course of the Project and that this information should be archived for future use. A number of significant climate-related changes were found by MBIS researchers and the monitoring system would help track changes as they continue. This region was cited as a bellwether of climate change for Canada.

The use of Traditional Knowledge (TK) as a monitoring/research tool was discussed. Within the aboriginal community plans are underway to develop some standards for traditional knowledge based data although scientists will have to do some work to develop a framework for using it in traditional scientific work. TK can provide local information about sensitivities at a much smaller scale that most models and can also indicate issues that are of great concern for the stakeholders.

Research and Collaboration

Researchers were reminded that Traditional Knowledge exists because lives depend on it. They were encouraged to do research as if their lives depended on it. There were a number of comments relating to both process and future directions for research. On the process side, it was noted that a multi-disciplinary project such as this requires a full time secretariat to facilitate exchanges of information and data. The project should also specify a common platform (such as a GIS) for data exchange. Dr. Cohen

was encouraged to write a paper describing what worked and what didn't in the MBIS process in order for other projects to build on the experience.

There were a number of suggestions for future directions for research. It was suggested that the findings be incorporated into studies of the Arctic as a whole. Another possible direction is to expand the research into an integrated study of multiple atmospheric stresses in the region. In the climate of funding cutbacks and few centrally generated pools of money for large studies such as this, it is likely that future studies in the region will have to be stakeholder driven and focused on their specific concerns such as ground water management, wildlife management, water quality and forest fire management.

Residents of the region seemed to feel optimistic that future research could be more regionally driven as opposed to the older model of southern scientists dropping in to conduct a study and then leaving. It poses a number of opportunities for collaboration in the Basin. It was pointed out that there are many scientists doing research in the Arctic and that annual, triennial or quadrennial review meetings may be a useful way to encourage communication and collaboration between the myriad of scientific interests. Reduced funds for research also may encourage collaboration to obtain more bang for the buck. Some commentators would like to see more collaboration between major research projects such as MBIS and the Mackenzie Basin GEWEX project. The Aurora Institute was mentioned as one agency that could help facilitate collaboration between research projects.

A number of times throughout the meeting speakers pointed out that the residents of the Mackenzie Basin contribute only a small portion of Canada's greenhouse gas emissions yet the they are likely to experience dramatic impacts of climate change. Residents felt that despite sociological changes in their communities, they could adapt to climatic changes as long as they weren't too rapid. Thus slowing the pace of climate change should be an important goal of Canada's policies.

Additional Comments from Joe Benoit

Scientific studies are useful snapshots of where you are, but you have to step back and make sure the big picture is where you want to go. Where is research going? Will scientific models keep getting bigger? Perhaps smaller models are better?

After the first MBIS workshop (1992), I gave up driving. If all of us in the North decided to do something it won't make any difference, so how can global emissions be controlled?

We need to know the risks and benefits of climate change. Risks - how do we know that no one died from climate change yet.? Benefits - I might be a farmer in a few years. As economic demands change, I would like to remain traditional, but not likely.

Back to TK and science, and the idea that people came in, did work and took off; there are too many "parachutes." What is needed is cultural immersion to create greater understanding, so that scientists see things the way aboriginal people do. Regarding training, we just had the furthest north graduation of aboriginal students in a resource management program, but we can't ignore elders. This helps to communicate technical information between generations. Scientific models don't tell us exactly where impacts will occur, so we need to address risks/benefits.

Comments from people I talked to represent a broad spectrum, so you get broad variation. Baseline data development has been started at community level.

Questions from the Audience

Joanne Barnaby, Dene Cultural Institute:

More recommendations:

1) Find a way to commit to development of clear language reports. Critical step to finish the project.

2) Create a follow up mechanism similar to the co-management concept. I caution you to see different needs and process of supporting TK. However, Co-management Boards' set up often pressures aboriginal members to "represent" TK. This is unrealistic

3) I like the idea of a mechanism of on-going monitoring including aboriginal participation. The Dene Cultural Institute is trying to garner support for workshops with elders to establish TK standards, including definitions, organization, needs, and clear guidance on methodologies for use. This speaks to needs with respect to training (local and scientist) and issues of access and ownership of information. Any researcher in the room will see the value and benefit of these studies.

4) Important for us in a climate change project to support stated research needs from communities with respect to climate change. e.g. include groundwater management, caribou management, water quality and

forest fire management.

5) Would like to hear from scientists in MBIS who are interested in actively supporting TK and collaborating with institutes such as Dene Cultural Institute. Interested in collaborating with open minded, sharing scientists.

Gunter Weller, University of Alaska-Fairbanks: The International Arctic Science Committee is launching similar research experiments in the Bering and Barents Sea regions, so this meeting has been helpful. I would like to see a concept that looks at Arctic as a whole, especially with respect to climate change assessment. The Arctic is a system that influences the global system, therefore the stakeholder community is a global community.

Henry Cole, University of Alaska-Fairbanks, former advisor to governor of Alaska:

Politics and Communications - this is a broader science problem of selling science to the public.

Science is an aspect of politics - identify, define and give concrete structure to your questions.

In the political realm this leads to action. Send message in non-jargon, non-probabilistic language.

If experts can't go out on a limb who can?

Decisions require 2 things: do you have to make a decision and do you have to make it now. There needs to be a special effort to develop messages and a language to make decision-makers decide to make decisions now.

Ross Benton, Canadian Forest Service, Natural Resources Canada:

1) Lots of discussion focused on people north of 60 N. Basin incorporates a lot of area south of 60 N and non-native communities as well.

2) As a researcher a number of problems were noted:

a) you have to have a secretariat which is data oriented and organizational to help the cross transfer of data; there are large amounts of non transferable data (e.g. different element data base, not just common climate data)

b) supply a common GIS or GIS support, or specify a public domain GIS software.

Chris Fletcher, BC Ministry of Forests:

We need a bit of work to incorporate TK to bring it into a framework that is useful in empirical culture.

From Decision-makers point of view:

- uncertainty is no longer an excuse

- climate change is a continental problem, not local.

Climate change is a controversial issue. Look out for the "mutual admiration club."

I struggle with bosses to get time and $$ to develop ways to account for uncertainty. Lots of stuff crosses my desk. Why should climate change be more important than anything else?

Manfred Lange, University of Muenster, Germany:

This has been a good learning experience. Given available resources, this is a tremendous achievement - lots of non-monetary work has gone into it. I would have wished for a bit more certainty/stringency on results. Concerning the issue of integration - results are unclear; I urge you to continue to try to accomplish this.

On the issue of local and native communities - you have set a model here with varying success (great success in involving people). I agree with monitoring - focus on places that are most sensitive (better placed to do this now). Also, remember that MBIS is just part of the larger globe.

The format of this meeting (Round Tables and posters) was action oriented - very effective way of bringing message across.

Sylvia Tognetti, University of Maryland:

TK exists because survival depends on it. Challenge

to science - how can we do science as if our life depends on it and communicate it? You should monitor against a worst case scenario and shift the burden of proof.

Kevin Jardine, Greenpeace:

There was a TV report shown in Alberta - the images with the climate change story were of happy warm weather activities. Communication strategy is absolutely critical. It is easier to communicate TK than elaborate mathematical models, and we need the pictures of negative effects.

David Grimes, Environment Canada:

I have some comments and a challenge.

Climate change is approaching an interesting phase. In October 1997, 160 countries will be trying to reach agreement on the next steps. Territorial, Provincial and Federal governments have been talking about climate change for the last 3 years - talking about a reasonable compromise on steps to move forward (same common objective - different pathways).

What is MBIS going to say to that community?

This is an important opportunity. The National Action Plan on Climate Change (NAPCC) was developed in 1991, but it wasn't until 1994 that it was recognized as a national document. NAPCC has 3 steps - mitigation, adaptation, and research. What steps do we have to take to be ahead of climate change?

This fall, we'll be evaluating progress made and challenges ahead. Make sure MBIS makes a strong statement. This process will generate NAPCC2 to cover the next 5 years.

In the 1990 Green Plan statement - Canada expressed concern about climate change and wanted to understand policy repercussions on 3 regions of Canada. We have to focus decision makers on steps they can take NOW in order to make a difference.

My Challenge: I'm the most senior member of Environment Canada here - what do you want me to say to the minister (2-3 key messages, and key recommendations to add to NAPCC)?

I thank Stew on behalf of Environment Canada - 6 years is a long time but you managed to keep things moving forward and focused.

Response from the Round Table

Joe Benoit: Use TK - wherever you want to do research, there is TK there. Local people can give you clues about where to go when, what. Ask for advice. Do research as if your life depends on it - agree that life depends on it. TK keeps you from being lost.

David Malcolm: All of us should follow up and do what we can and continue collaborating with MBIS scientists to help them translate their reports to Plain Language so communicators can speak with understanding and raise voices so politicians will hear.

Rodney White: Take to the Minister the following: We now know impacts of trends in the state of the environment. Use community-based studies on how factors/sectors interplay and incorporate TK.

Jim Bruce:

1) Climate change that IPCC says is discernible is now evident in Mackenzie Basin. Climate change is happening here now.

2) Impact on people of the North will be large yet they caused little of the problem.

3) People of the North can adapt if we slow down rate of climate change.

4) Need to set up system to monitor where climate change will be felt first and greatest.

Stewart Cohen: In response to Chris Fletcher regarding the "mutual admiration club:" this is a result of mutual learning - that's what interdisciplinary, cross cultural research is all about A wide range of people agreed to work together, and the challenge is to keep it open.

The next study will need driving from the region - there is no "Green Plan II." Our role will be as a resource for projects that Northerners would like to start.

We want assistance in getting the word out in plain language, but we need to become aware of how to do that.

Does this scenario make a difference to your vision of the future. Most of you have said "Yes" - at least in the long term. There appears to be a tension between being a victim and raising a regional voice at a higher level. Perhaps the latter will prevail, supported by planned adaptation and monitoring.

All photos by I. Hartley, May 7, 1996.

3

WATER

Future Water Levels and Flows for Great Slave and Great Bear Lakes, Mackenzie River, and Mackenzie Delta

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Abstract

Scenarios for future changes in water levels and flows throughout the Northwest Territories portion of the Mackenzie Basin are analyzed. As regards climate change, it is likely that the effects of higher precipitation will be more than compensated for by higher evaporation and evapotranspiration, so that water levels and flows are expected to be lower (except as affected by higher Arctic Ocean levels in the Mackenzie Delta area), spring breakup is expected to be earlier, and early spring flows are expected to be higher. The seasonal distribution of water levels and flows is also influenced by the operation of man-made reservoirs.

The following analyses were carried out in the NWT portion of the Mackenzie Basin:

1. *1973-92 monthly lake water balance analyses for Great Slave and Great Bear lakes, involving computation of evaporation and evapotranspiration by the water balance method (including use of precipitation formally corrected for undercatch, detailed analyses of lake outflow and ungauged lake inflow, and start-of-month lake level adjustments)*
2. *1973-92 relationships between air temperature and evaporation and evapotranspiration*
3. *1973-92 monthly routing through Great Slave and Great Bear lakes (including detailed analyses of log-log stage-outflow relationships, use of EC Lake Routing Model, and study of climate change scenarios)*
4. *1973-92 daily Mackenzie mainstem routing from Great Slave Lake to Mackenzie Delta (including use of EC SSARR-type SIMMAC Streamflow Routing Model, and study of climate change scenarios)*
5. *1982-93 daily (and at times three-hour) routing through Mackenzie Delta to Arctic Ocean (using EC 1-D Hydrodynamic Model to analyze 85-channel configuration of delta)*

Because of the tremendous regulating effect of Great Slave and Great Bear lakes, climate change will not produce sudden or dramatic water level and flow changes. However, because of a combination of reduced inflows due to climate change and reduced summer flows due to the operation of man-made reservoirs, future water levels for Great Slave Lake, and future mainstem and delta water levels and flows, may be significantly lower than the historically lowest values experienced during the summer and fall of 1995.

Introduction

The Mackenzie River and its major tributaries, the Athabasca, Liard and Peace rivers (**Figure 1**) represent one of the largest river systems in the world (MRBC, 1981). It is by far the largest Canadian river flowing to the Arctic Ocean. The river system is the lifeline of the area through which it flows, and its waters have several uses. Navigation, one of the main uses, extends from the Athabasca River and Great Slave Lake to the Arctic Ocean and beyond.

Environment Canada is in the forefront of studies of climate change and resulting impacts. The MBIS (Mackenzie Basin Impact Study) has evaluated potential impacts of different types due to climate change. GEWEX (Global Energy and Water Cycle Experiment), an international scientific project, seeks improved understanding of physi-

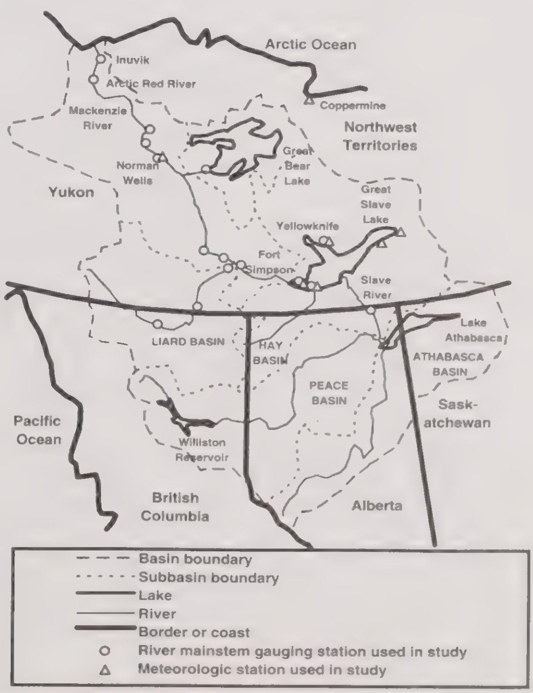

Figure 1. Mackenzie Basin.

cal environment processes and the effects of climate change. The Mackenzie and Mississippi basins are the North American pilot project areas for GEWEX studies.

Environment Canada in Yellowknife has worked closely with MBIS and GEWEX, and has received partial funding from GEWEX to utilize its data base and apply its models to route historic flows with and without climate change through the NWT portion of the Mackenzie Basin. Flows are routed through Great Slave and Great Bear lakes, down the Mackenzie mainstem, and through the Mackenzie Delta to the Arctic Ocean. The project ties in closely with four-day forecasts made daily and long-term water-level projections to October 31 made two or three times each summer for navigation interests by Environment Canada in Yellowknife.

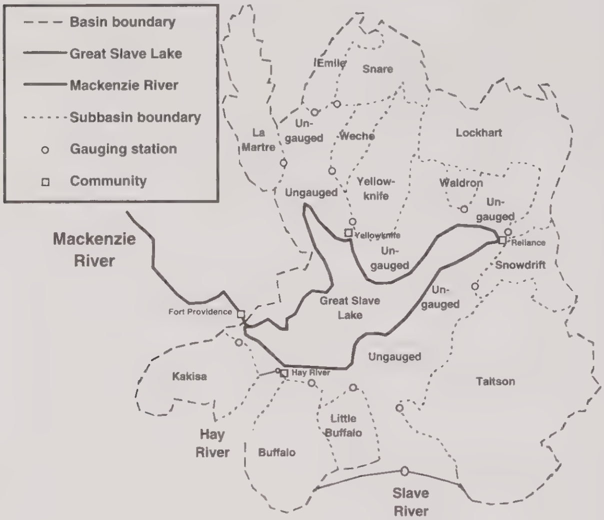

Figure 2. Great Slave Lake — Tributary Inflow.

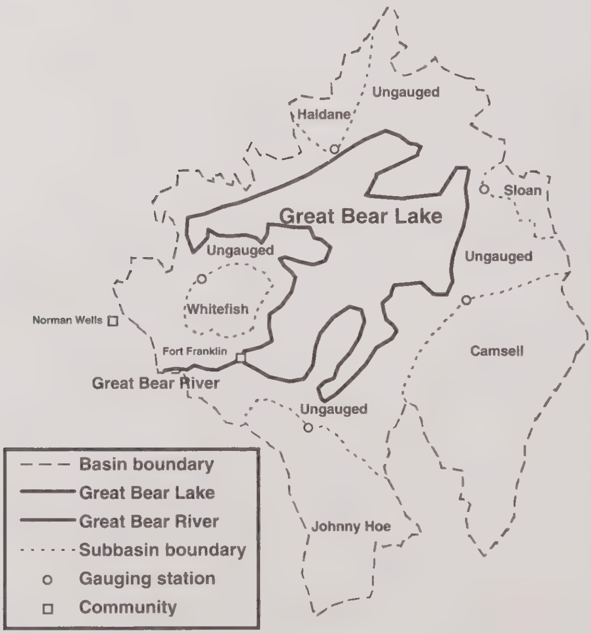

Figure 3. Great Bear Lake — Tributary inflow.

Study Area and Study Period

The current study deals with the part of the Mackenzie Basin situated in the Northwest Territories. The importance of river hydraulics, navigation, and dredging issues below Great Slave Lake are covered in reports by Public Works Canada and Transport Canada (1978) and the Canadian Coast Guard (1987) which assess navigation hazards on the river, possible future channel improvements, and other factors. An evaluation of two severe July 1988 NWT storms by Jasper and Kerr (1992) demonstrates the importance of closely monitoring tributary inflows and of flow routing to accurately forecast impacts on mainstem Mackenzie and Liard river water levels for navigation, ferries, and flood-prone communities.

Analyses to date have been carried out for the period 1973-92 for main water balance and routing analyses, and for 1938-96 for special tasks. The 1973-92 time period is now being expanded to 1973-95. Adding 1993-95 is complicated by the closing of many small hydrometric stations in recent years, particularly those on smaller tributaries to Great Slave and Great Bear lakes. The stations closed were those with relatively few lakes and indicative of ungauged areas, whereas those retained were commonly stations below large lakes or in the downstream part of lake-studded basins. Special procedures are hence being used to estimate ungauged inflow around Great Slave and Great Bear lakes for the period 1993-95.

Great Slave and Great Bear Lakes

Location Maps

Figures 2 and 3 show tributaries of Great Slave and Great Bear lakes. Gauged tributary inflows to the two lakes were required for all analyses. Both gauged and estimated ungauged tributary inflows were required for lake analyses involving climate change studies, because percentage changes in tributary gauged

and ungauged inflows were used.

Figure 4 shows tributaries of the Mackenzie River between Great Slave Lake and the Mackenzie-Liard confluence. Tributary inflows to this reach were required (1) to compute gauged and ungauged tributary inflow to the Mackenzie River, and (2) to compute Great Slave Lake outflows from flows of the Mackenzie River at Fort Simpson, flows of the Liard River near the Mouth, gauged and ungauged inflow between Great Slave Lake and the Mackenzie-Liard confluence, and other factors, for use in deriving stage-outflow curves.

Historic Water Levels

Figure 5a shows Great Slave Lake annual mean water levels for the period 1939-95. Annual mean levels varied by 0.569 m, from a minimum of 156.301 m in 1945 to a maximum of 156.870 m in 1964. Both extremes occurred before the creation of Williston Reservoir on the Peace River in British Columbia in 1968. Subsequent to this date, the minimum annual water level was 156.362 m in 1995, almost the same as the pre-Williston minimum annual water level.

Figure 4. Fort Providence to Fort Simpson — Tributary inflow procedures.

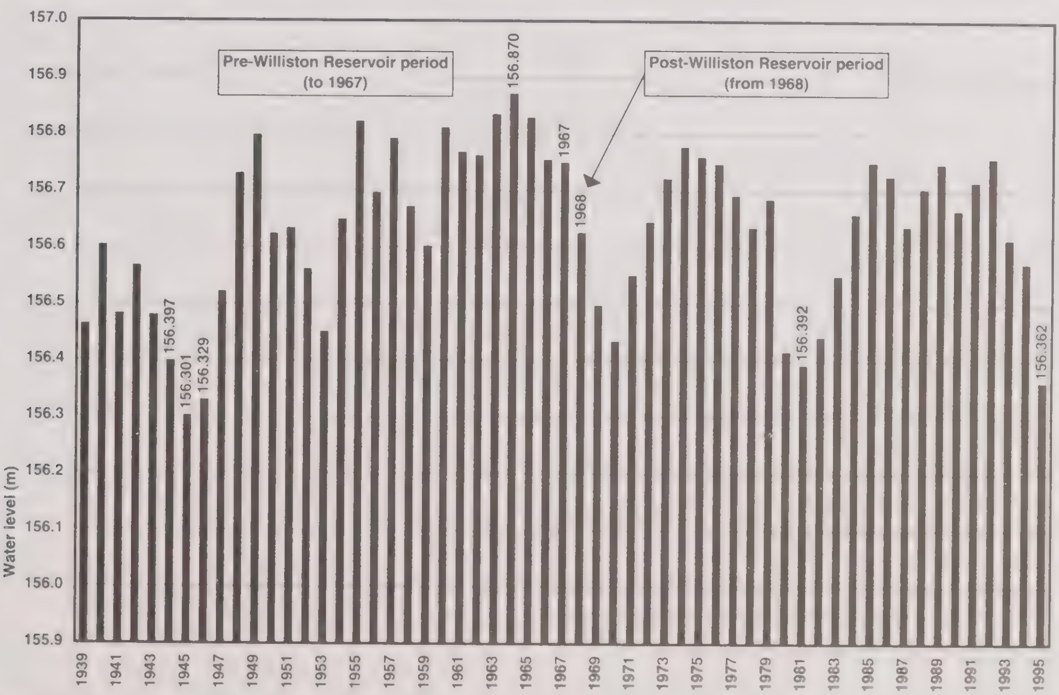

Figure 5a. Great Slave Lake at Yellowknife Bay — Annual mean water levels, 1939–95

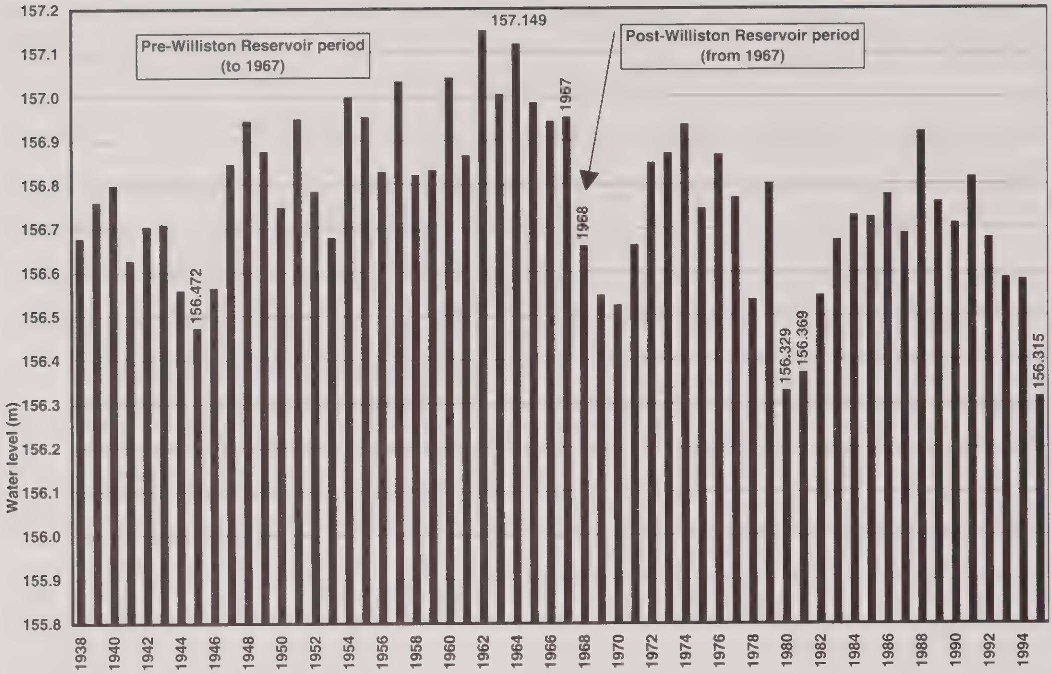

Figure 5b. Great Slave Lake at Yellowknife Bay — Aug.–Sep. mean water levels, 1939-95.

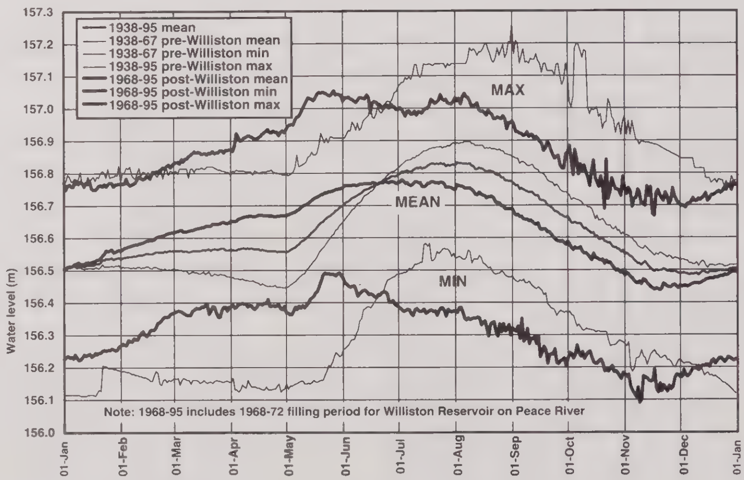

Figure 5c. Great Slave Lake at Yellowknife Bay. 1938–95 water levels, pre- and post-Williston Reservoir periods.

August-September water levels are critical to navigation planning. **Figure 5b** shows Great Slave Lake August-September mean water levels for the period 1938-95, varying by 0.834 m, from a low of 156.315 m in 1995 to a high of 157.149 m in 1962. Before Williston Reservoir was created in 1968, the lowest August-September mean water level was 156.472 m in 1945, 0.157 m higher than the corresponding value after Williston Reservoir was created.

Figure 5c shows the variation during the year of the mean of daily mean water levels of Great Slave Lake, the minimum of daily minimum water levels, and the maximum of daily maximum water levels for the period 1938-95, and also for the periods before and after the creation of Williston Reservoir in 1968. **Figure 5d** presents the same information for the period after the creation of Williston Reservoir in 1968, plus individual curves for 1995 and the first part of 1996. Higher winter Peace River flows after the 1968-72 reservoir filling period and corresponding lower summer flows apparently contribute to Great Slave Lake minimum daily water levels being from one to two decimeters higher in the latter part of the winter and spring, and slightly more than one decimeter lower during the summer

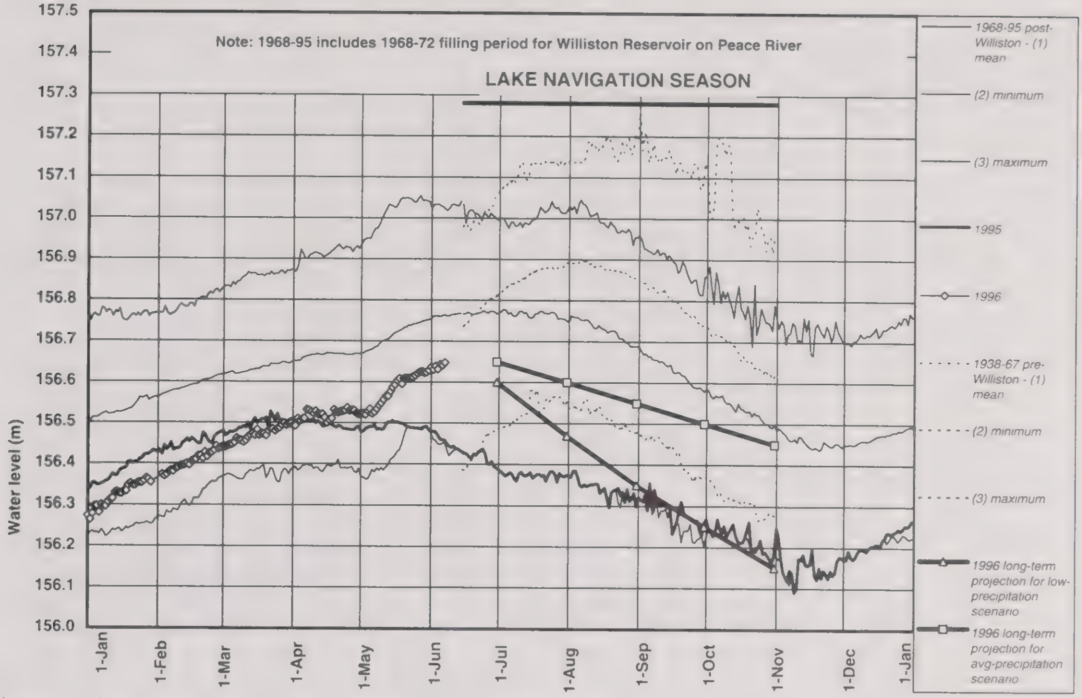

Figure 5d. Great Slave Lake at Yellowknife Bay. 1938–96 water levels.

and fall.

During the period 1943-95, historic Aug.-Sep. mean lake water levels for Great Bear Lake varied by 0.900 m, from 155.600 m in 1948 to 156.500 m in 1961 (**Figure 6a**). **Figure 6b** shows the variation during the year of the mean of daily mean water levels, the minimum of daily minimum water levels, and the maximum of daily maximum water levels for the period 1943-95, an individual hydrograph for 1995, and a water level measurement made during the first part of 1996 for this lake.

Annual lake water level trends reflect a combination of natural phenomena and changes in the seasonal variation of inflows to Great Slave Lake from the Peace/Slave river system due by the filling and operation of Williston Reservoir above Bennett Dam in the headwaters of the Peace River. As regards natural phenomena for large water bodies, data for Great Bear Lake, which is not affected by upstream artificial regulation, indicate that lake outflows and levels fluctuated in a narrower range after 1984 than prior to 1984. A similar trend was noted in studies of long-term (85-year) cycles which relate not to flow but to flow variability, as expressed by lake storage change (Vutga, 1968). Even so, it is evident that outflows from Williston Reservoir play an important role in defining the seasonal pattern of Great Slave Lake water levels. Williston Reservoir is recharged each year during spring and summer runoff, the extra water being released during the following winter to produce electrical energy. Outflows from the Williston Reservoir are hence commonly below what natural flows would have been during summers and considerably above during winters.

Graphs of daily water levels for Great Slave and Great Bear lakes showed a number of spikes on the hydrographs, in part due to short-term wind effects. Because accurate values of lake levels at the start and end of each year and each month are required for lake routing purposes, start-of-month lake levels affected by such wind spikes were adjusted, as illustrated for Great Slave Lake for sample year 1976 on **Figure 7**. For this lake, only water levels at Yellowknife Bay were used because a full record of geodetic lake levels is available there, whereas records at other stations have extensive voids, are not referenced to geodetic control, are not given to an identical geodetic datum, or have other problems. For Great Bear Lake, early water level records at the Port Radium station and recent records at the Hornby Bay station were combined to create a single table, based on a water level transfer across a bay of the lake.

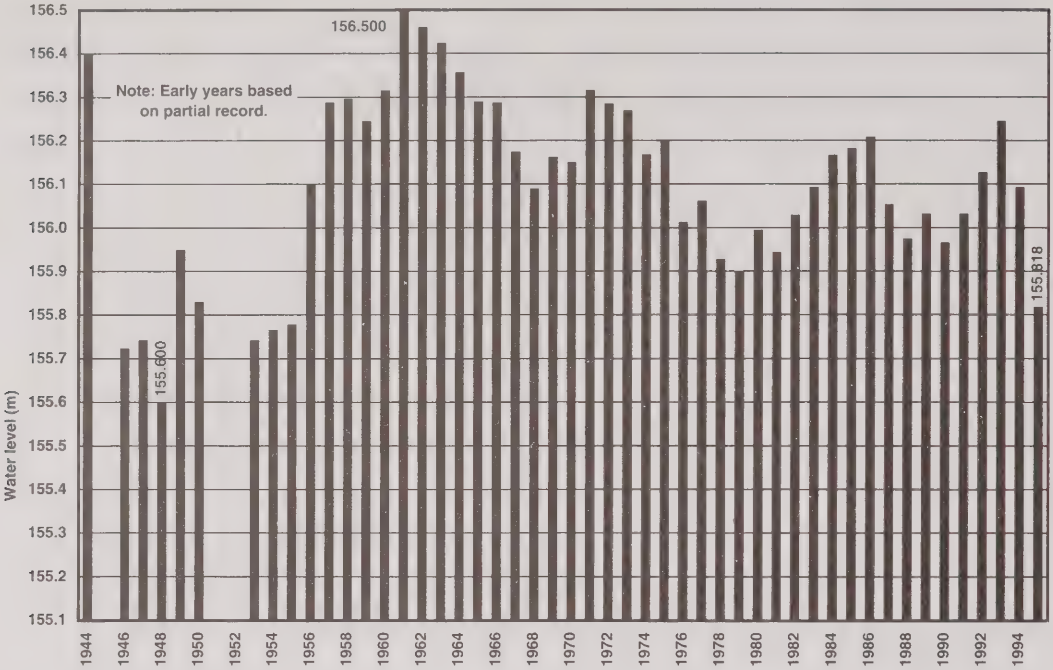

Figure 6a. Great Bear Lake — 1944–95 Aug.–Sept. mean water levels.

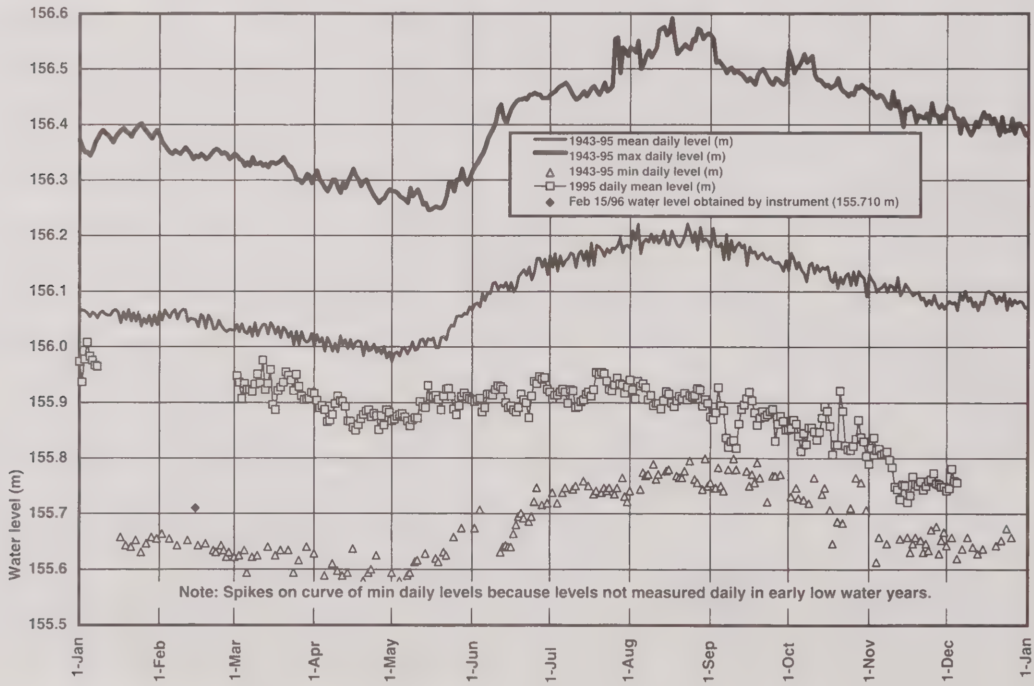

Figure 6b. Great Bear Lake — 1943–96 daily water levels.

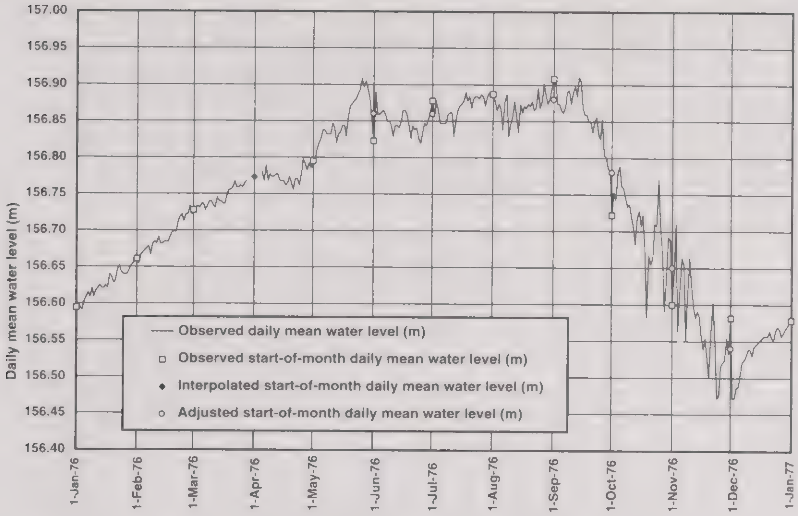

Figure 7. Great Slave Lake — Sample start-of-month lake level adjustments.

lake outflows (when available). Further analyses related to this subject are underway at the present time.

Only one stage-outflow curve was required for Great Bear Lake, because the lake outlet remains relatively free of ice during the winter. **Figure 8a** shows the log-log stage-outflow curve for Great Bear Lake, and **Figure 8b** shows the corresponding arithmetic stage-outflow curve.

Precipitation

Monthly mean precipitation and temperature data (and some measured evaporation data) were obtained for stations in the vicinity of Great Slave and Great Bear lakes. Daily mean precipitation data (Metcalfe & Ishida, 1994; Reid, 1994) corrected for undercatch were subsequently obtained and converted to monthly values.

For Great Slave Lake, uncorrected precipitation data were obtained from six stations on the shores of Great Slave Lake (Fort Providence, Fort Resolution, Hay River, Reliance, Snowdrift and Yellowknife), and corrected precipitation data were obtained for five stations in the vicinity of the lake (Fort Smith, Hay River, Reliance, Snare Rapids and Yellowknife) (**Figure 9a**).

Lake Stage-Outflow Curves

Stage-outflow curves for Great Slave and Great Bear lakes were prepared by plotting observed monthly mean lake levels versus observed monthly mean outflows.

The Great Slave Lake outlet freezes over during the winter, so a family of stage-outflow curves is required - one curve for the open-water season, and one for each month with ice conditions. Ice effects in this area are of concern to ferries and navigation vessels and to other interests (Hicks, 1994). Two sets of curves were derived. The first set was created by plotting monthly mean lake levels versus monthly mean lake outflows, as calculated from flows of the Mackenzie River at Fort Simpson, the Liard River near the Mouth, local inflow between Great Slave Lake and the Mackenzie-Liard confluence, and other factors. The ungauged inflow from the latter area was derived using two gauged streams in the tributary area (Jean Marie and Trout rivers) and two gauged streams adjacent to the tributary area (Kakisa and Willowlake rivers). The second set of curves was created by plotting monthly mean lake levels versus approximate monthly mean measured

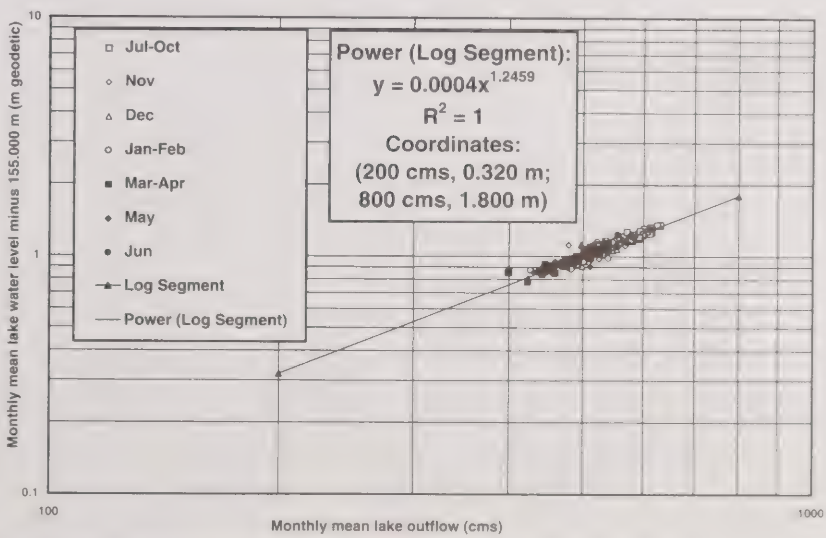

Figure 8a. Great Bear Lake — Stage-outflow relationship on log-log scale.

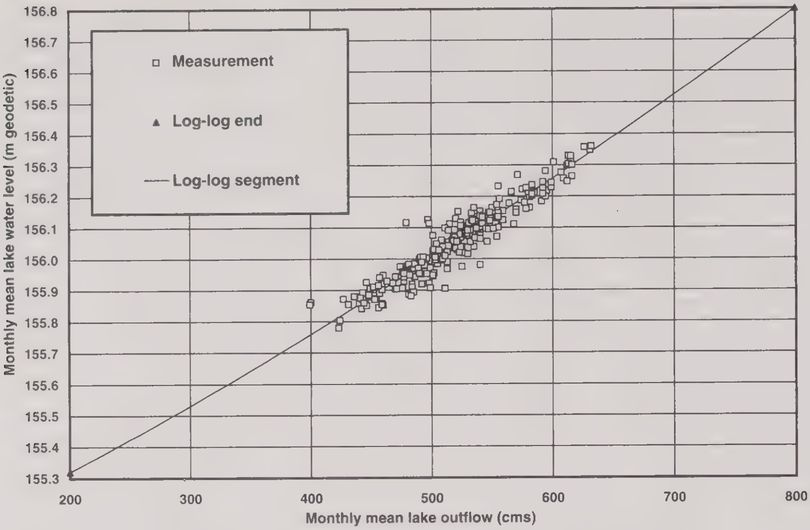

Figure 8b. Great Bear Lake — Stage-outflow relationship on arithmetic scale.

For Great Bear Lake, uncorrected precipitation data were obtained for five stations in the general area (Coppermine, Fort Franklin, Fort Norman, Norman Wells and Port Radium), and corrected precipitation data were obtained from four stations in the vicinity (Coppermine, Fort Good Hope, Norman Wells and Snare Rapids) (**Figure 9b**). Precipitation data were sparse for the two stations on the shores of Great Bear Lake (Fort Franklin and Port Radium) and the one at the confluence of the Great Bear and Mackenzie rivers (Fort Norman). Precipitation data were more complete for stations further from the lake, such as at Norman Wells and Coppermine. However, Norman Wells is located near the Mackenzie Mountains to the west, while Coppermine is located on the Arctic Ocean to the northeast. Fortunately, this occurs in the case of Great Bear Lake, with its much lower flow contribution and its downstream off-channel location, in comparison with Great Slave Lake.

Monthly mean meteorologic values for Great Slave

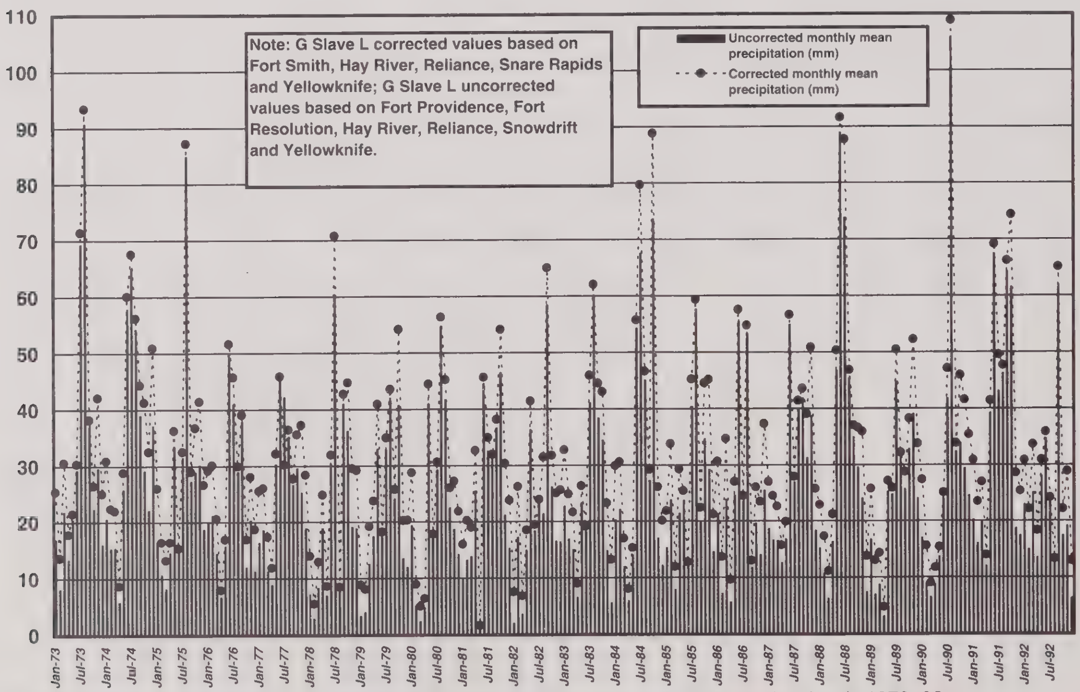

Figure 9a. Great Slave Lake — Corrected and uncorrected monthly mean precipitation (mm), 1973–92.

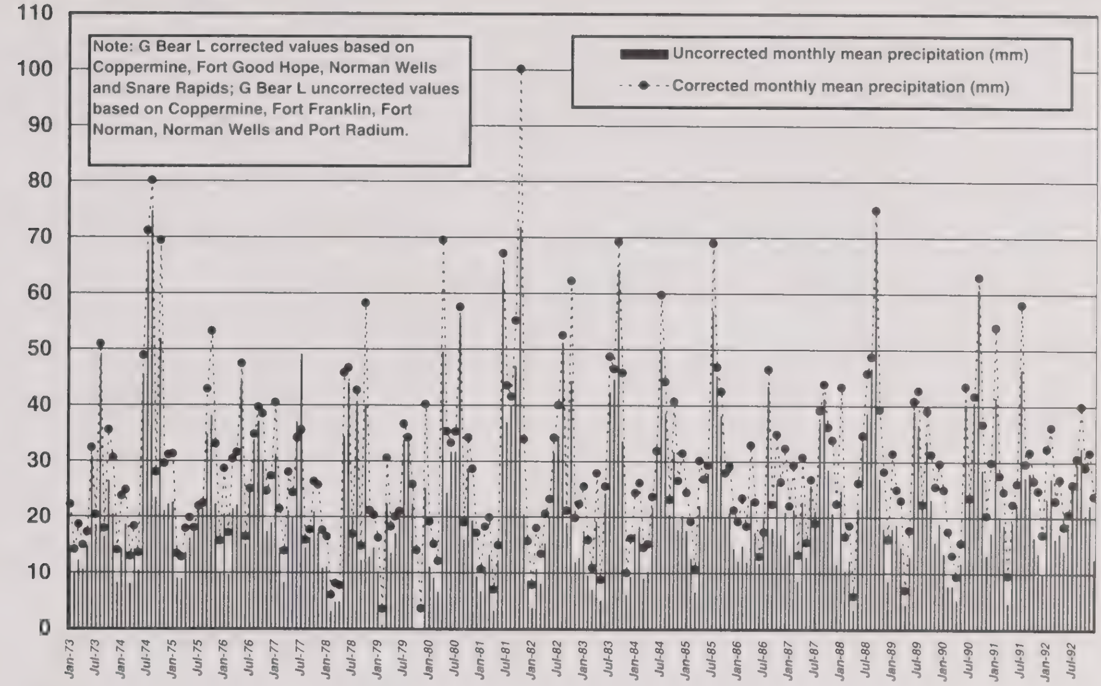

Figure 9b. Great Bear Lake — Corrected and uncorrected monthly mean precipitation (mm), 1973–92.

and Great Bear lakes were calculated as simple means of values at stations around the lake, computed for each month using data from all stations with data for that month. Monthly mean corrected and uncorrected precipitation for the period 1973-92 are shown on **Figure 9a** for Great Slave Lake and on **Figure 9b** for Great Bear Lake.

Tributary Inflows

Monthly mean inflows were computed from daily mean inflows for all gauged rivers entering Great Slave and Great Bear lakes and for the area immediately downstream from Great Slave Lake (**Figures 2, 3 and 4**). Flows from ungauged areas were estimated by assuming that the unit runoff from ungauged areas in any particular month was equal to the unit runoff from the gauged basins with few lakes and with flow data for that month.

Average seasonal patterns of flow and unit runoff for tributaries of the two lakes are shown on **Figures 10a and 10b** (six smaller tributaries of Great Slave Lake with many lakes), **Figures 11a and 11b** (six smaller tributaries

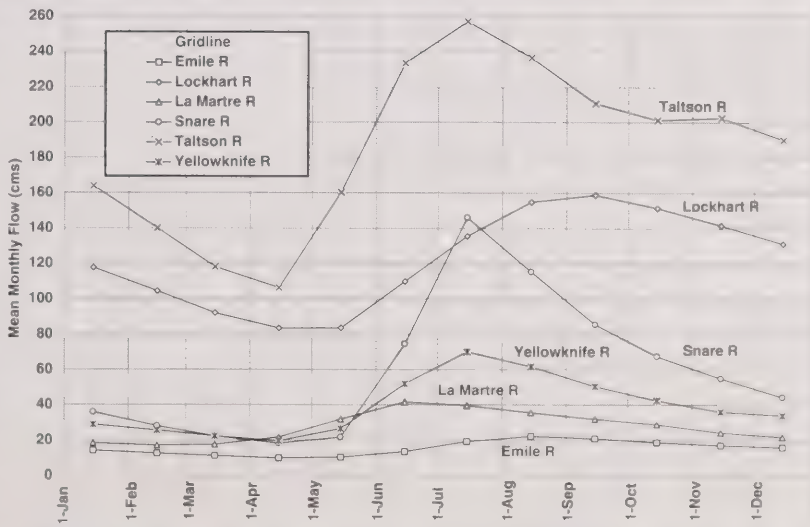

Figure 10a. Great Slave Lake — Seasonal flow patterns for gauged tributaries with many lakes (1973–92).

of Great Slave Lake with relatively few lakes), and **Figures 12a and 12b** (five tributaries of Great Bear Lake). There is often little or no correlation between flows of adjacent tributaries, because some basins have considerable natural (and in a few cases artificial) regulation due to lakes and depressions, whereas other basins have relatively little storage. The ungauged basins in the area generally have relatively little natural storage (and no artificial storage).

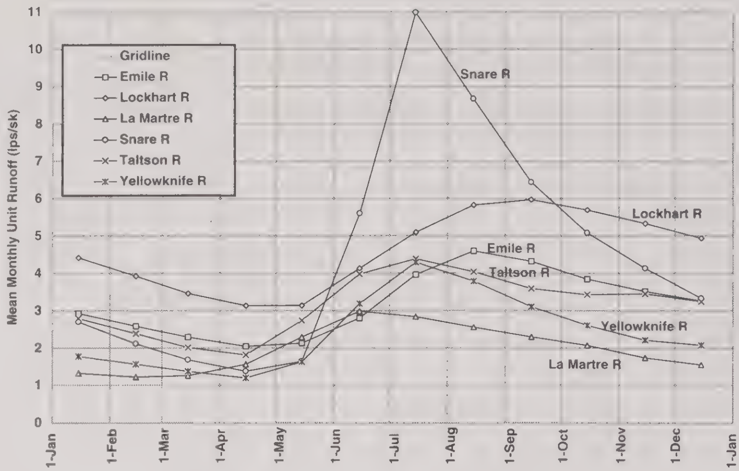

Figure 10b. Great Slave Lake — Seasonal unit runoff patterns for gauged tributaries with many lakes (1973–92).

For Great Slave Lake, gauged flows from six local tributaries with relatively few lakes (Buffalo, Kakisa, Little Buffalo, Snowdrift, Waldron, and Wecho rivers) were used to compute ungauged inflow. Gauged flows from the Slave and Hay rivers and six relatively small local gauged rivers with lake-studded basins (Emile, La Marte, Lockhart, Snare, Taltson, and Yellowknife rivers) were not used to compute ungauged inflow. As noted above, flows from ungauged areas were estimated by assuming that the unit runoff from ungauged areas in any particular month was equal to the unit runoff from the gauged basins with few lakes having flow data for that month.

In the case of Great Bear Lake, five tributaries have streamflow records (Camsell, Haldane, Johnny Hoe, Sloan, and Whitefish rivers). Flows from ungauged areas were estimated by assuming that the unit runoff from ungauged areas in any particular month was equal to the unit runoff from the Haldane and Whitefish basins for that month. Lake-studded Camsell Basin has a relatively constant outflow, which is not typical of the ungauged portion of the drainage basin of Great Bear Lake. Camsell River flows were therefore not used to compute ungauged inflows. Of the other four gauged tributary basins, the Johnny Hoe River is by far the largest and has the most complete record. While the Johnny Hoe River does have more variable seasonal flows than the Camsell River, including higher spring peak flows in May and June, water balance calculations involving approximate ungauged inflow to Great Bear Lake indicated that ungauged inflow should be still higher in these two months. Also, May and June unit runoff values for the Haldane, Sloan, and Whitefish rivers are often approximately two to four times that of the Johnny Hoe River. It was also found that the Sloan Basin is not typical of the ungauged areas.

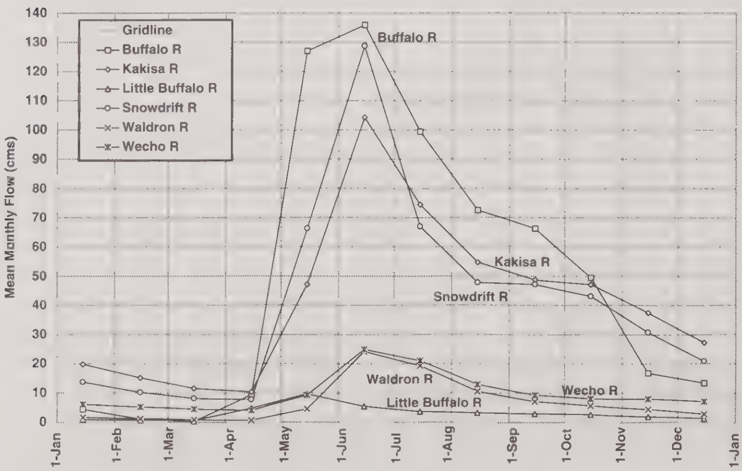

Figure 11a. Great Slave Lake — Seasonal flow patterns for tributaries with few lakes, used to compute ungauged inflow (1973–92).

Lake Water Balance Procedures Required for Lake Routing

For lake routing purposes, initial lake water balance procedures are carried out to define "inflow available for outflow" (also referred to as net basin supply) - unaccounted-for inflow which does not evaporate or otherwise disap-

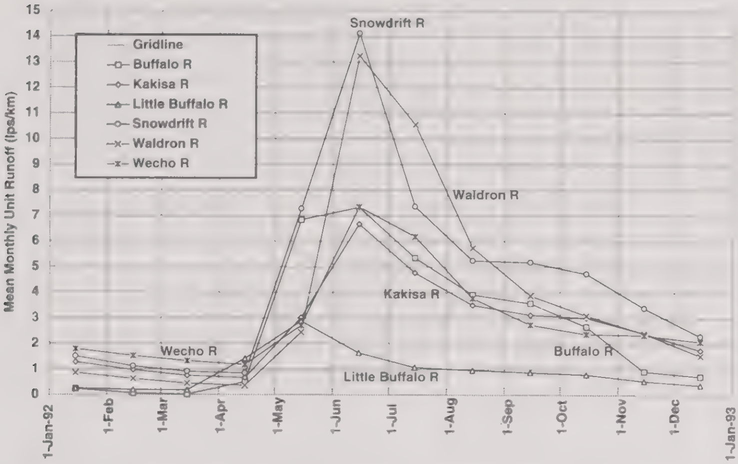

Figure 11b. Great Slave Lake — Seasonal unit runoff patterns for tributaries with few lakes, used to compute ungauged inflow (1973–92).

pear, such as by infiltration. If all inflow can be accounted for, and infiltration is insignificant, then inflow available for outflow is equal to evaporation by the water balance method (true evaporation plus or minus estimate errors), but with the opposite sign.

When climate change is not considered (such as during model calibration, or the study of man-made works), inflow available for outflow is commonly defined as ungauged surface inflow plus precipitation minus evaporation. If ungauged surface inflow is specifically defined for other reasons, inflow available for outflow can comprise precipitation minus evaporation. And if corrected precipitation is also defined for other reasons for the full time period, inflow available for outflow can be specified as the negative of evaporation by the water balance method. Routing results will be the same whichever of the three alternatives is selected.

When climate change is considered, and surface inflow is assumed to change, ungauged inflow must be specifically defined in order to be changed by specific percentages. If precipitation and evaporation are considered to remain constant or to vary by the same amount and in the same direction (a scenario at times assumed out of necessity), inflow available for outflow is defined as precipitation minus evaporation. If corrected precipitation is specifically defined for other reasons for the full study period, inflow available for outflow can be specified as the negative of evaporation by the water balance method. Routing results will be the same whichever of the two alternatives is selected.

The scenarios in which (1) corrected precipitation varies with climate change but evaporation does not, and (2) both corrected precipitation and evaporation vary with climate change but by different amounts, both require that corrected precipitation be specifically defined. They are not analyzed in this paper as regards water balance computations and lake and river routing, but are dealt with below under the heading Evaporation by Water Balance Method to facilitate future work.

Routing through Great Slave and Great Bear Lakes and down Mackenzie River to Mackenzie Delta

Lake routing through Great Slave and Great Bear lakes was done on a monthly basis because of the immense size of the lakes and daily water level fluctuations due to wind effects, instrumentation, and other factors. In contrast, downstream river routing was done on a daily basis. The EC Lake Routing Model, developed by Environment Canada in Yellowknife, was used to carry out monthly lake routing.

The SIMMAC Streamflow-Routing Model, developed by Environment Canada in Yellowknife, uses daily mean flows (Jasper & Kerr, 1994; Kerr & Jasper, 1995; Kerr &

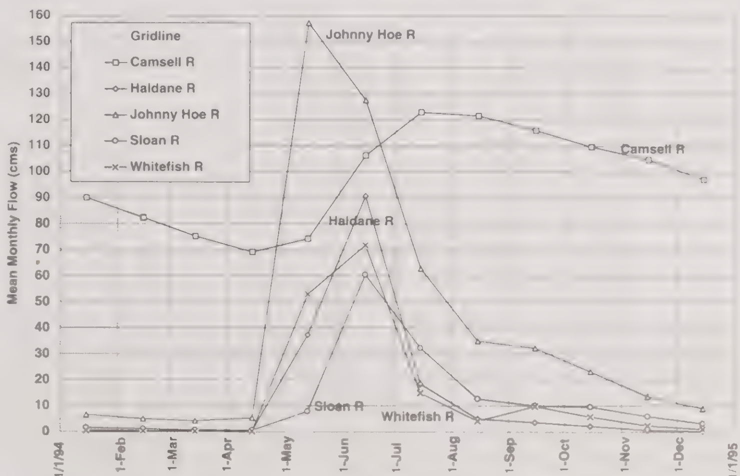

Figure 12a. Great Bear Lake — Seasonal flow patterns for gauged tributaries (1973–92).

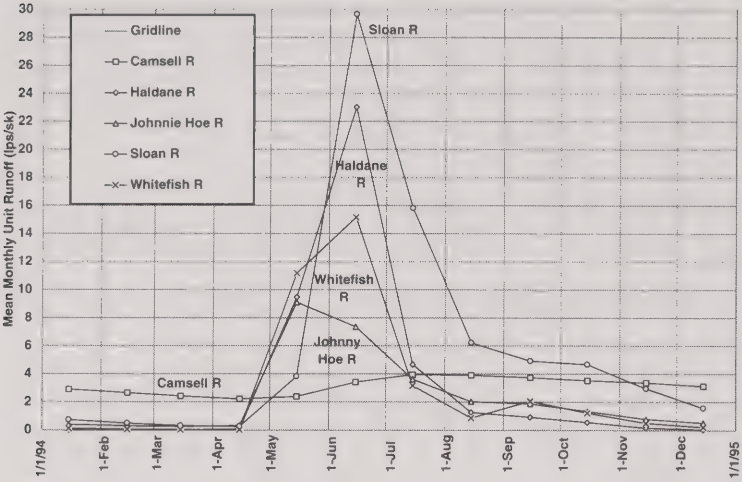

Figure 12b. Great Bear Lake — Seasonal unit runoff patterns for gauged tributaries (1973–92).

Miyagawa, 1994a). It has been used for the past several years to produce the Mackenzie River Water Level Forecast. The model uses the US Army Corps of Engineers SSARR algorithm to route flows, that is, to take into account the effects of lag time and channel storage. When calibrating this model, it is run for full navigation seasons in a long-term simulation mode, as opposed to a short-term forecast mode. During open-water conditions, the model can be used to convert downstream routed flows to computed water levels using stage-discharge curves, when downstream water levels are required.

Routing of daily Mackenzie mainstem flows was carried out for the period 1973-92, for historic flow and flows modified for climate change, using the above-described SIMMAC Model. Monthly lake outflows were first converted to daily lake outflows using a smoothing technique. The SIMMAC Model was then applied in the simulation mode between the outlet of Great Slave Lake and the Mackenzie River at Fort Simpson. Tributary inflows were computed as the sum of historic tributary inflows between Fort Providence and Strong Point (computed as described above for Great Slave and Great Bear lakes, but on a daily basis) and historic daily flows for the Liard River near its mouth. Daily tributary inflows between Fort Simpson and Norman Wells and between Norman Wells and Arctic Red River were next computed, using the method described above for defining tributary inflows (other than for the Great Bear River, which drains Great Bear Lake). Between Fort Simpson and Norman Wells, gauged indicator streams used were the Redstone, Root, South Nahanni and Willowlake rivers (Great Bear River flows added separately). Between Norman Wells and Arctic Red River, gauged indicator streams used were the Arctic Red, Carcajou, Mountain and Ramparts rivers. Finally, daily flows were routed from Fort Simpson to Norman Wells, and from Norman Wells to Arctic Red River.

As a first step, before output from hydrologic models became available, routing models were tested using inflows arbitrarily reduced by constant percentages. In separate computer runs, historic surface water inflows for the period 1973-92 were reduced arbitrarily by 0, 10, 20, 30 and 40 percent. The results serve only to indicate how the system would function under hypothetically severe conditions, and

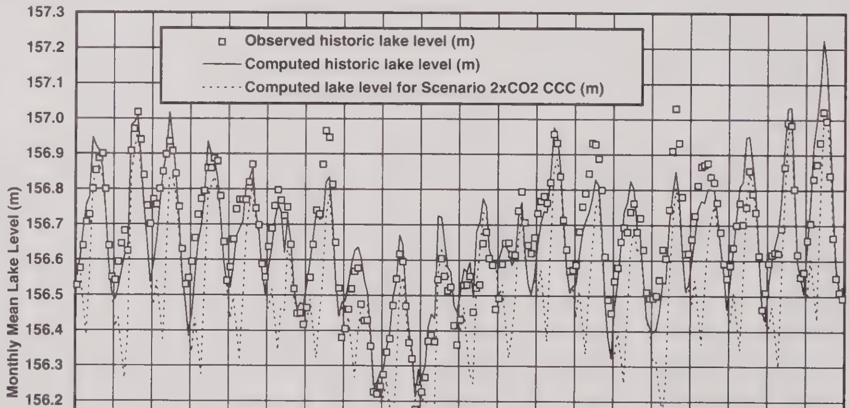

Figure 13a. Great Slave Lake — Observed and computed water levels (1973–92).

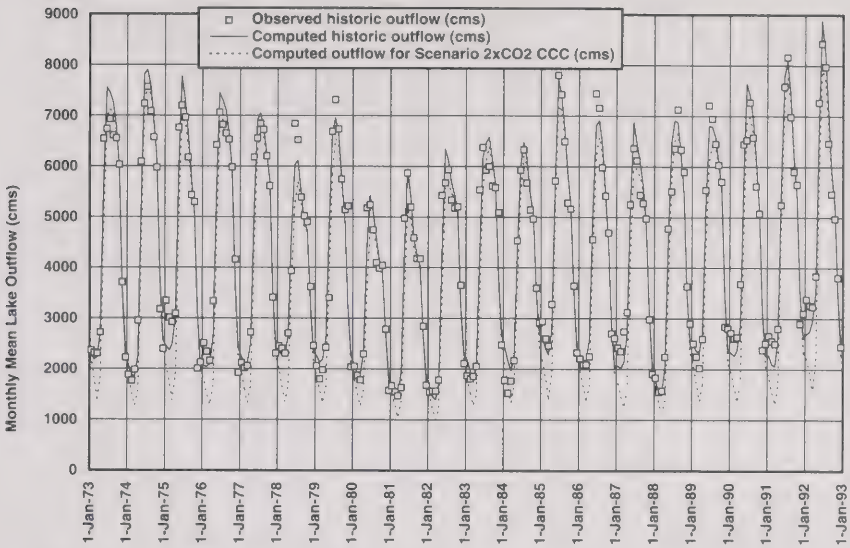

Figure 13b. Great Slave Lake — Observed and computed lake outflows (1973–92).

results from the above-mentioned hydrologic model were used directly for the Great Bear, Mackenzie, and Peel subbasins. Three subbasins were combined for the Liard Basin, and ten subbasins were combined for the Great Slave Lake Basin. It must be stressed that combining ten subbasins to obtain percentage inflow changes to 1973-92 historic inflows to Great Slave Lake is only a first approximation. Firstly, the results from the above-mentioned hydrologic model were derived from 1951-80 data, and the corresponding percentage changes were applied to 1973-92 data. Secondly, while the 1973-92 base case data (historic flows) are not reported here.

The results of climate model runs and hydrologic model runs made by others were then used. Climate models produce results such as temperature and precipitation, which are used as input to hydrologic models, which in turn produce runoff from relatively small local drainage areas for the base (historic) case and for different climate change scenarios. The present study deals with both historic flows and climate change flows, computing percentage changes in the tributary inflows derived by the latter hydrologic models, applying these percentage changes to historic flows, and simulating the movement of water through Great Slave and Great Bear Lakes and down the Mackenzie system.

Results from a University of Waterloo hydrologic model (Soulis, Solomon, Lee & Kouwen, 1995) analyzing three 2xCO2 (double the carbon dioxide in the air) scenarios (CCC Scenario, GFDL Scenario, and Composite Scenario originated by MBIS) were used to compute percentage changes in subbasin inflows. The three scenarios are described in the latter reference and will not be dealt with in detail here. The percentage changes derived from the hydrologic model results were applied to all 1973-92 historic inflows, and the resulting flows were then routed through Great Slave and Great Bear lakes and on downstream to the Mackenzie River at Arctic Red River at the head of the Mackenzie Delta.

Percentage changes in flow computed from subbasin

include the effects of upstream storage, the percentage changes derived in the current study do not yet include the effects of routing through Williston Reservoir, Lake Athabasca and other water bodies upstream from Great Slave Lake in British Columbia, Alberta and Saskatchewan. Results from Peace River and Peace-Athabasca Delta routing models, in the form of modified Slave River inflows to the NWT, can be used when they become available. Further hydrologic model results, including results using corrected precipitation for the entire Mackenzie Basin, are scheduled to be released in mid-1996 by researchers using hydrologic models.

Figure 13a shows the results of routing through Great Slave Lake in terms of lake levels. The graph indicates observed and computed monthly mean water levels for Great Slave Lake for the period 1973-92. Computed values are shown both without climate change (for calibration) and with climate change (2xCO2 CCC Scenario). **Figure 13b** shows the same information for Great Slave Lake outflows. It is evident that winter and summer outflows for the climate change scenario are consistently lower than outflows without climate change.

Figures 14a, 14b, 14c and 14d show a comparison of observed and computed historic daily mean flows for the Mackenzie River at the head of the Mackenzie Delta (Arctic Red River). The indicated deviations between observed and computed values during breakup and freezeup are to be expected, because, unlike the 1-D Model, the

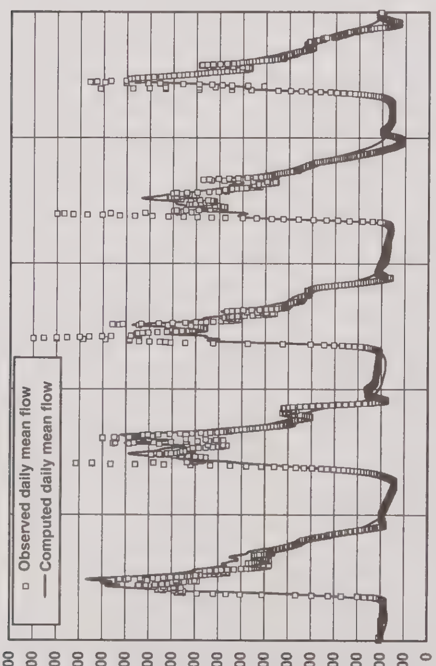

Figure 14a. Mackenzie River at Arctic Red — Results of routing historic daily mean flows (1973–77).

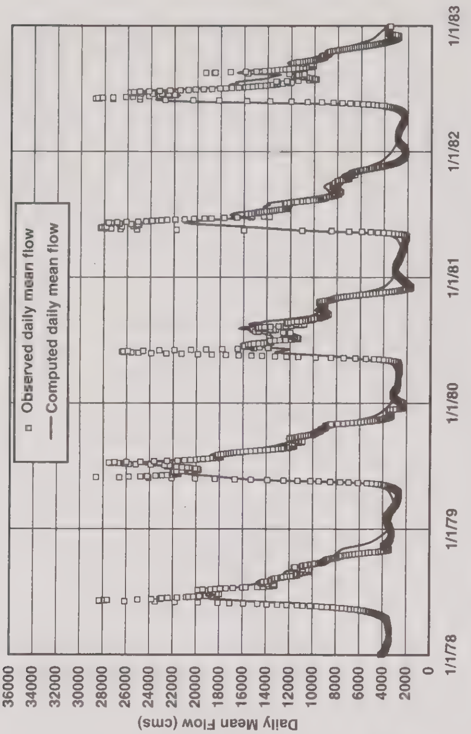

Figure 14b. Mackenzie River at Arctic Red — Results of routing historic daily mean flows (1978–82).

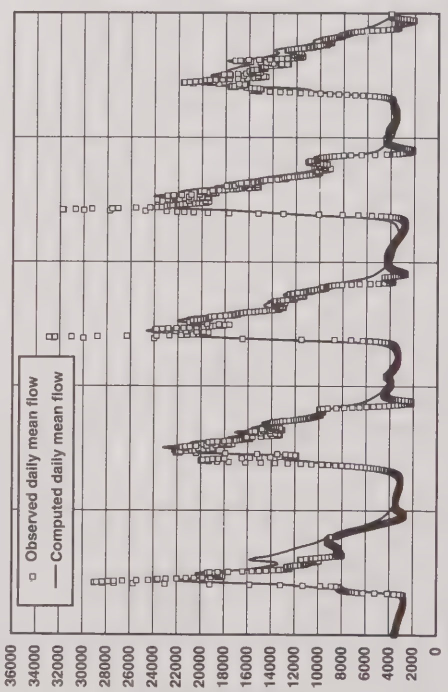

Figure 14c. Mackenzie River at Arctic Red — Results of routing historic daily mean flows (1983–87).

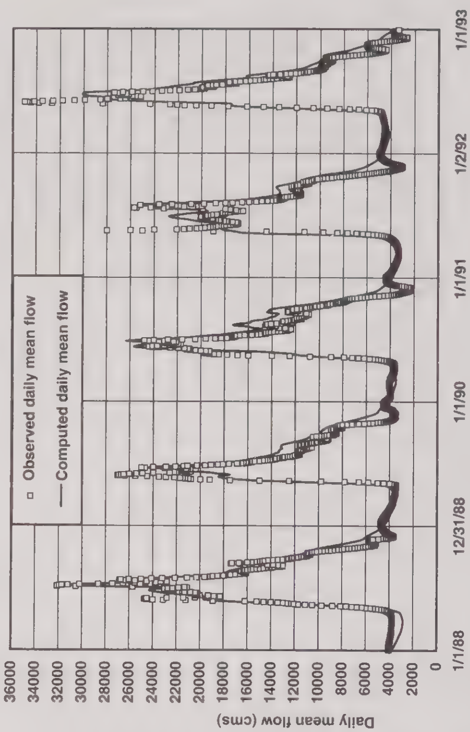

Figure 14d. Mackenzie River at Arctic Red — Results of routing historic daily mean flow (1988–93).

SIMMAC Model does not take into account storage of water under ice and as ice. Also, at breakup, especially during icejams, water levels are measured, but flows are estimated from the measured water levels and other considerations, and are hence approximate. Computed historic daily mean flows (rather than observed historic daily mean flows) were used for comparison of historic flows to flows computed for climate change scenarios, because changes are of particular interest in such studies (**Figures 15a, 15b, 15c and 15d**). The latter figures illustrate that winter flows for the climate change scenario are consistently lower than winter flows without climate change.

Mackenzie Delta

The Mackenzie Delta 1-D Hydrodynamic Model computes water levels and flows at all points in the delta, based on upstream boundary conditions consisting of delta inflows from the Mackenzie River at Arctic Red River and the Peel River at Fort McPherson, and downstream boundary conditions comprising water levels near the Arctic Ocean (Kerr, 1993; Kerr & Miyagawa, 1994b; Miller, 1993). The delta is simulated as an interconnected network of 85 channels, using a time interval of one, three, six or 24 hours. The 1-D Model can be applied with either historic boundary conditions or boundary conditions modified due to climate change or man-made activities, and can be used for both summer and winter flow conditions.

Daily mean observed flows for the period 1982-93 were routed through the delta, using the 1-D model to define the flow/sediment distribution and the effects of ocean storm surges in the delta. The period 1973-81 was not analyzed because there are insufficient recorded water level data near the ocean for that period. Because essential boundary conditions required to model the Mackenzie Delta include both delta inflows and water levels near the ocean, the evaluation of water levels and flows in the delta due to climate change requires estimates of future changes in ocean levels as well as modified inflows to the delta. With this input, the Mackenzie Delta 1-D Hydrodynamic Model can be used to define the effects of modified inflows and ocean levels on water levels and flows throughout the Mackenzie Delta. This is scheduled to be done after further data polishing and rerouting upstream from the delta, and after consideration of water storage and movement outside of the 85-channel configuration during ice breakup periods and superfloods.

Evaporation by Water Balance Method

Computation of evaporation by the water balance method is useful for general studies of evaporation, as well as for analyses of changes in evaporation with changes in factors such as air temperature, which is expected to increase in future climate change scenarios. In routing, evaporation must be used as input for climate change scenarios when both (1) surface inflows change, as described above, and (2) lake precipitation and evaporation also change but not by the same amount (or precipitation changes and evaporation does not).

The results of current climate change models of others include precipitation and temperature, but not formal lake surface evaporation. The strategy used, therefore, was to determine whether historic changes in evaporation computed by the water balance method are a function of air temperature (and other variables as well), and to utilize the relationship, if found, to derive evaporation values for climate change scenarios.

Mean evaporation values for Great Slave and Great Bear lakes were estimated by the lake water balance method. This method derives evaporation (in cms) as the total lake inflow (gauged and ungauged tributary inflow plus precipitation, in cms) minus lake outflow (in cms) minus lake storage change (in cms). Because lake surface evaporation computed by this method involves differences between large numbers with appreciable errors of estimation, the result includes both evaporation and errors due to assumptions - such as when estimating ungauged inflow and procedures used to adjust precipitation. The result is hence referred to as evaporation computed by the lake water balance method - to distinguish it from true evaporation.

Computation of lake evaporation by the lake water balance method had three objectives: (1) to gain insight into mechanisms other than evaporation affecting the water-balance computations; (2) to analyze relationships between evaporation and temperature; and (3) to permit the introduction of estimates of changes in evaporation in the future, as discussed above. The analyses were extremely useful in connection with the first goal, particularly as regards improving estimates of ungauged surface inflow. But the variations in monthly mean values indicated that the results often represent more than just evaporation, and were much less useful for the second and third goals. As one example, storms may occur over Great Bear Lake but not over meteorologic stations or vice versa (especially in the case of stations at Norman Wells near the Mackenzie Mountains and Coppermine near the Arctic Ocean), and errors introduced show up in the evaporation-by-balance values. Another example is the change in lake storage with changing lake water temperatures (Meredith, 1975), though this factor was partially eliminated by using longer time inter-

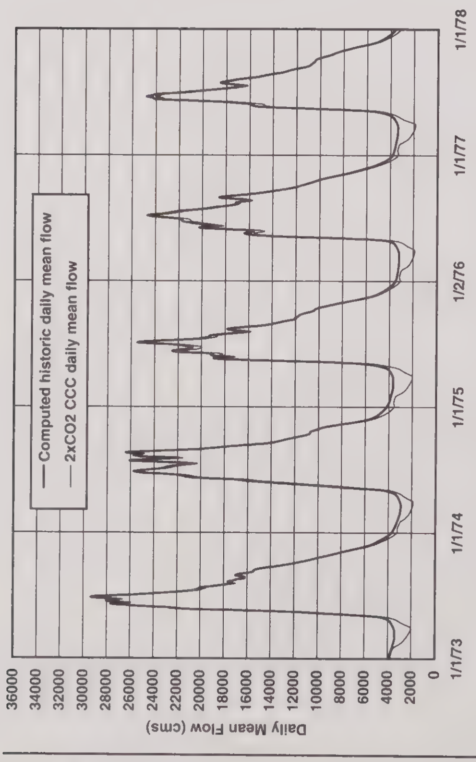

Figure 15a. Mackenzie River at Arctic Red — Computed historic and Scenario 2xCO2 CCC flows (1973–77).

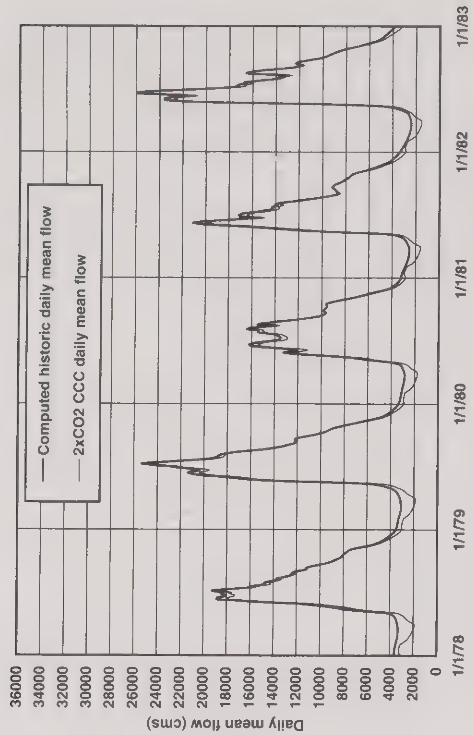

Figure 15b. Mackenzie River at Arctic Red — Computed historic and Scenario 2xCO2 flows (1978–82).

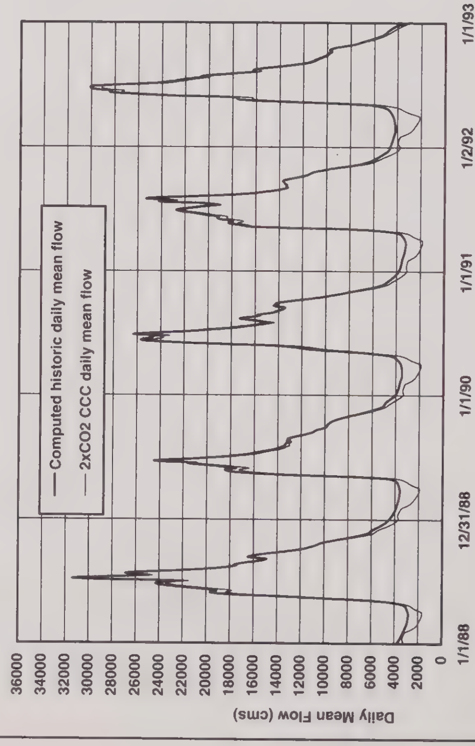

Figure 15c. Mackenzie River at Arctic Red — Computed historic and Scenario 2xCO2 CCC flows (1983–87).

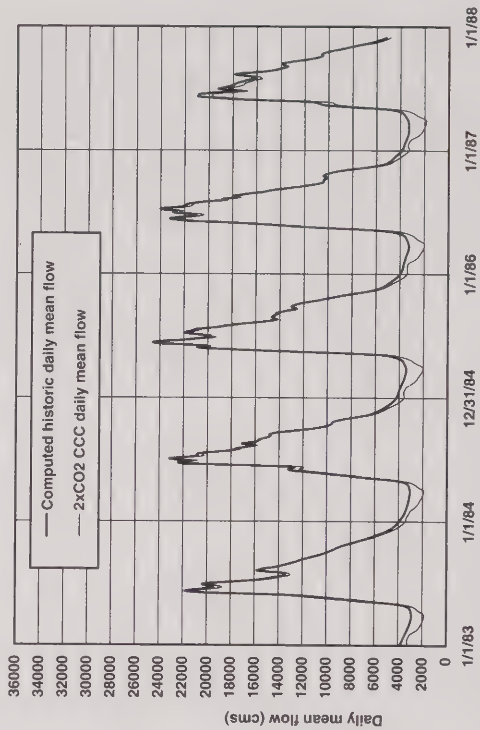

Figure 15d. Mackenzie River at Arctic Red — Computed historic and Scenario 2xCO2 CCC flows (1988–92).

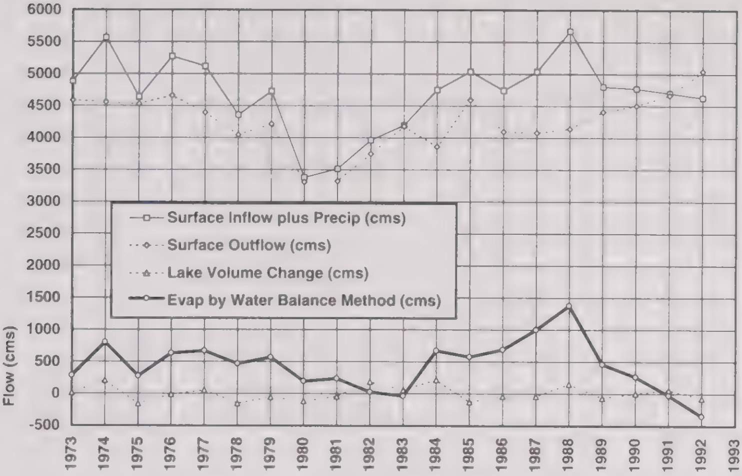

Figure 16a. Great Slave Lake — Annual water balance (cms) — (1973–92).

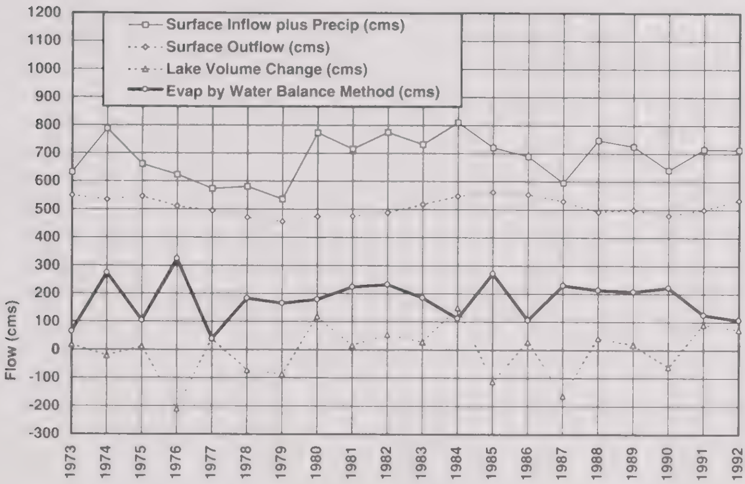

Figure 16b. Great Bear Lake — Annual water balance (cms) — (1973–92).

vals, as discussed below. The resulting scatter on plots of air temperature versus lake evaporation and air temperature versus peripheral evaporation/evapotranspiration masked any relationship between evaporation and air temperature - which was found to have a dominant influence on evaporation in studies in Southern Alberta (Nkemdirim & Purves, 1994a, 1994b) - if such a relationship does in fact exist in the Northwest Territories.

In order to avoid the effects of changing lake storage with changing lake water temperatures, and for other reasons, water balance computations were carried out on an annual basis (**Figures 16a and 16b**), as well as on a monthly basis. Three time intervals per year (Jan-Jun, Jul-Oct, and Nov-Dec) were also used to define mean seasonal evaporation (**Figures 17a and 17b**). These water balance computations were useful in pointing out years when and areas where further investigation of basic data is required, particularly for Great Slave Lake. For instance, if evaporation during a particular year is zero or negative when computed by the water balance method (**Figure 16a**), and storage change with water temperature and infiltration can be neglected, then either corrected (increased) precipitation is still too low, surface inflow is too low, or surface outflow is too high. These questions are being investigated at the present time.

Conclusions

Because of the tremendous regulatory effects of Great Slave and Great Bear lakes, climate change will not produce sudden dramatic flow and water level changes in the Northwest Territories portion of the Mackenzie Basin. However, while lower projected inflows to Great Slave and Great Bear lakes reduced lake water levels by only a few decimeters in the analyses, the resulting lower lake outflows are of concern. This is particularly so for the Mackenzie River downstream from Great Slave Lake, where low summer and fall flows cause navigation problems, and where low winter and spring flows contribute to ice related problems at river crossings. Also, for the Mackenzie Delta, further studies are required to analyze the effects of changed peak and low flows, and new seasonal flow distributions.

Further results from global climate models, hydrologic models, and Peace River and Peace-Athabasca Delta routing models, and estimates of Arctic Ocean water-level changes, can be used as additional input to NWT routing models to define in still more detail the effects of alternative future inflows and ocean levels on water levels and flows in the NWT portion of the Mackenzie Basin.

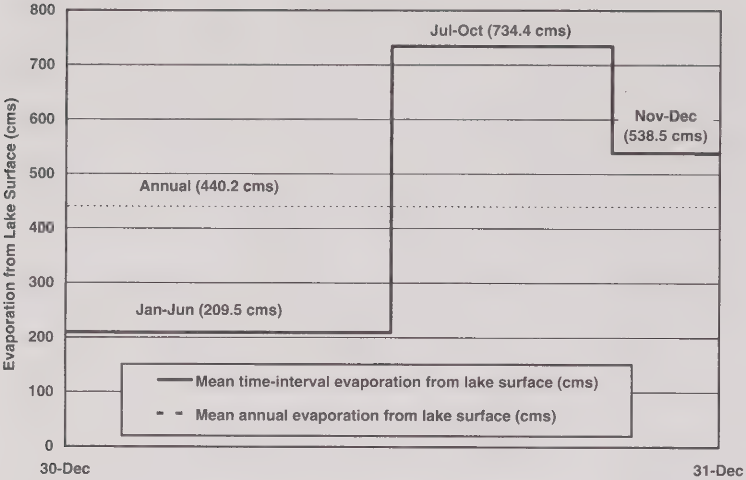

Figure 17a. Great Slave Lake — Evaporation by lake water balance method (1973–92).

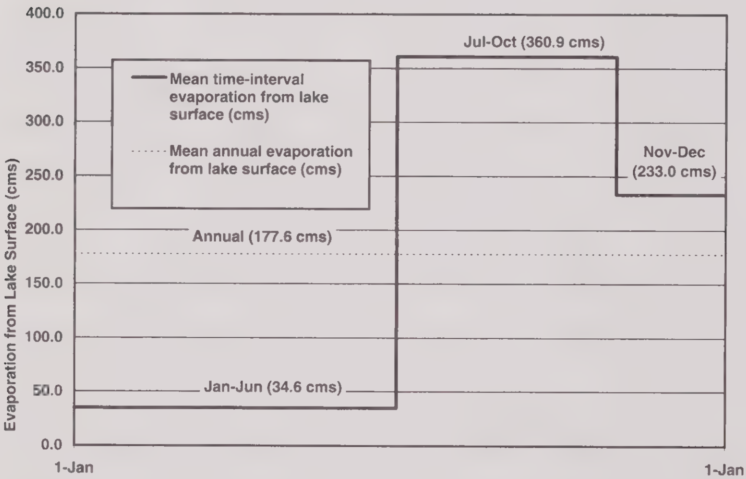

Figure 17b. Great Bear Lake — Evaporation by lake water balance method (1973–92).

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Suspended Sediment Travel Time Estimates for the Mackenzie Delta

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Introduction

During periods of high flow, often induced by up stream precipitation events or snowmelt, suspended sediment concentrations usually resemble a slug if plotted as a sediment hydrograph (called a pycnograph). Attenuation occurs as the slug travels downstream (see **Figure 1**). It is important to consider the sediment travel time such that sampling of the same location on the sediment hydrograph occurs, that is, the same water. The sediment travel time are usually based on regression results and for practical purposes, considered static. These times are used for sampling, and the examination of the sediment fluxes provides a partial indicator of deposition, erosion, and load movement, whose rates may be altered due to flow regime changes. The fluxes can also be linkage to the transport of contaminants.

Modelling Methodology

Computer modelling has been undertaken to estimate suspended sediment transport for multi-channel networks, as outlined in Fassnacht (1994), with an intermediate product being suspended sediment travel times. These travel time are based on the assumption that suspended sediment moves at approximately the same velocity as the water in which it is transported. The estimation based on the flow velocity seems appropriate, as no other estimates have been found in the literature.

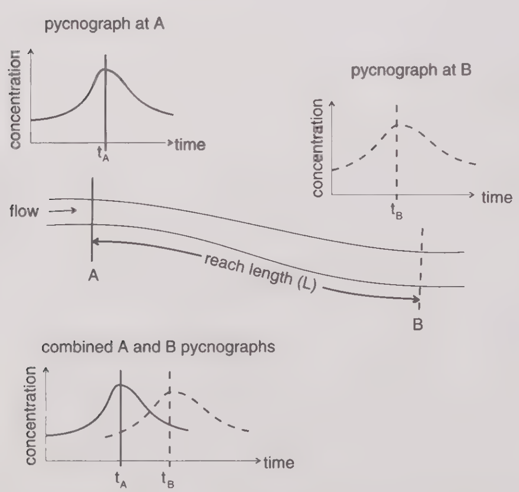

Figure 1. Suspended sediment slug attenuation

The computer modelling is based on a linkage of two existing models. The linked model (FOSH-MC) calculates flow from Environment Canada's ONE-D hydrodynamic flow model (as outlined by Water Modelling Section, 1988), and the suspended sediment transport component is calculated using the RIVFLOC model developed by Krishnappan (1991). The reader is advised to see the individual model manuals (Water Modelling Section, 1988 and Krishnappan, 1991) or Fassnacht (1994) for an in-depth description of each model, and Fassnacht (1996) for the linkage procedure.

The FOSH-MC model iteratively solves for the reach flows and nodal water levels for a specific date. These flows and water levels are used to assemble the hydraulic data with the sediment data to calculate the sediment concentrations in each reach and the total daily load at each of the network nodes. The ONE-D model implicitly solves the flows in each reach and the water levels at each node of a multi-channel network. Using initial travel time estimates, mean reach velocities are computed, and then flow-weighted travel time averages are calculated. This procedure is iterated until the travel time estimates converge. A convergence criteria of 0.01 days or 14.4 minutes was used for the Mackenzie Delta simulations. (This is approximately an order of magnitude better than is required for the flow model input.) The time calculation using a flow-weighted average thus considers a nodal budget about confluences and bifurcations.

Application

In conjunction with Environment Canada's NOGAP study objectives related to sediment, the model has been applied to the Mackenzie Delta, NWT (see **Figures 2a** and **2b** for the location map and model schematic, respectively).

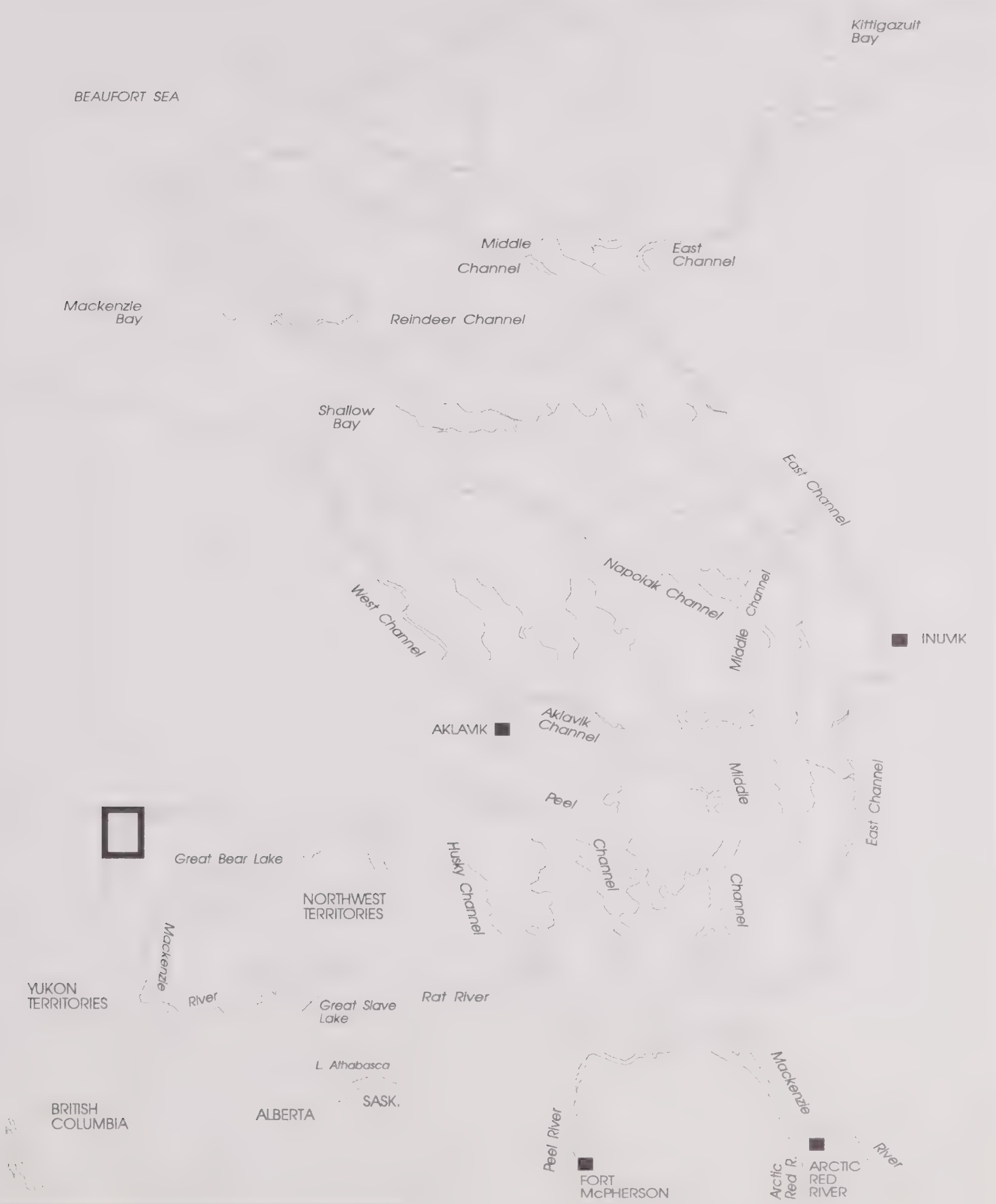

Figure 2a Location map of the Mackenzie Delta

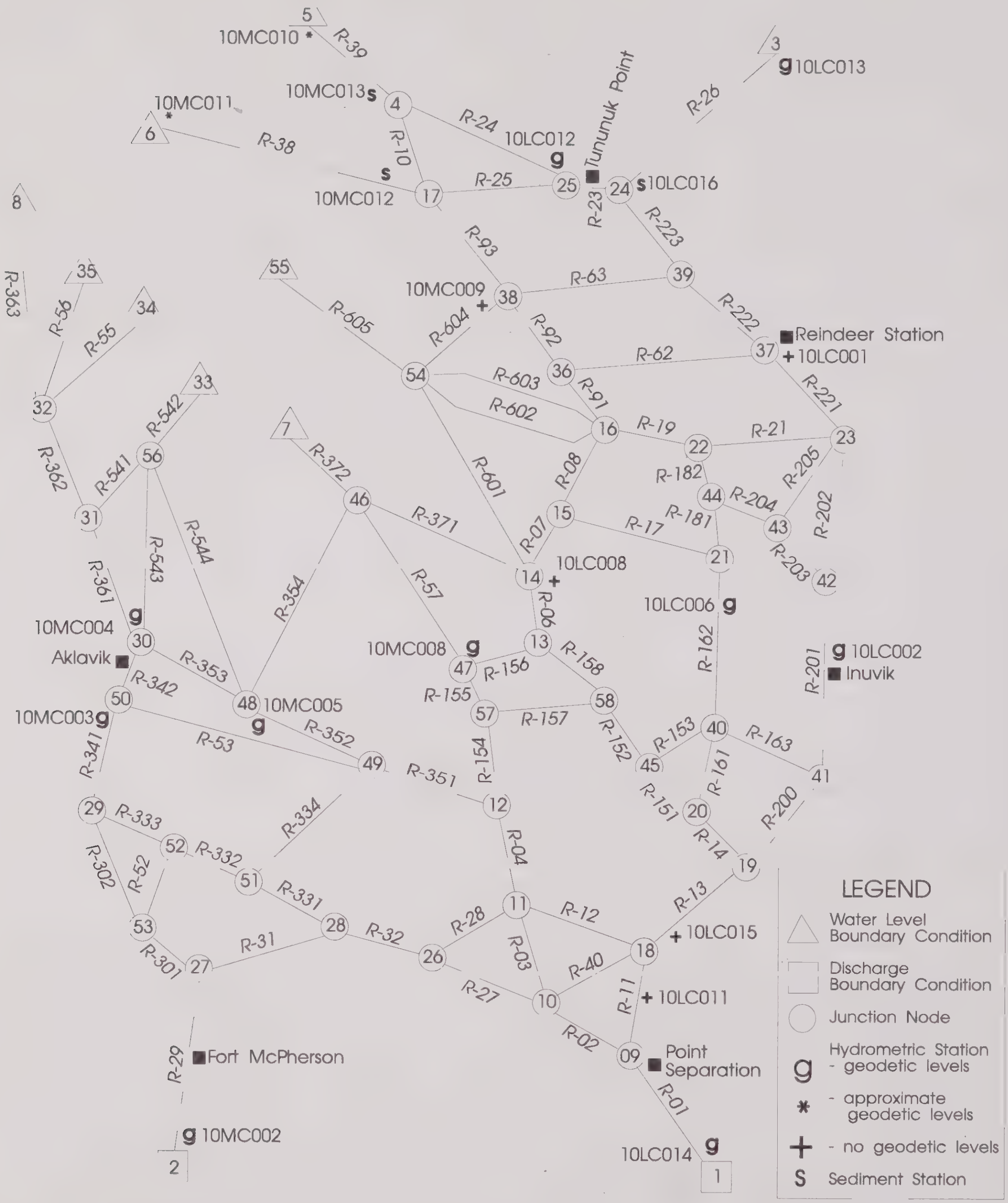

Figure 2b Mackenzie Delta model schematic (configuration 2A)

The FOSH-MC model uses three sets of hydrometric stations in the delta that are operated by Water Survey of Canada, as presented in **Table 1**. The upstream flows and downstream water levels are used as boundary conditions for the model, and the mid-transect water levels are used for model calibration and verification. The water levels, and subsequently the open water flows, are recorded continuously at most of the WSC stations. However, the suspended sediment concentrations and particle size distributions are only measured periodically, and can be as infrequent as twice yearly at some stations. As well, the sampling protocol, that is the timing of sample taking, is based on field logistics and intuition. This necessitates the establishing of a scientific basis for the timing of suspended sediment sampling.

Results

The calibration of the model used the mid-July 1993 flow event. The August 1991 and 1993 events were used for verification. Four other high flow events were also modelled. The estimated suspended sediment travel times for nine events are presented in **Table 2**. The mid-July 1993, early July 1988 and mid-August 1991 isochrone plots illustrate the significant travel time differences for different flow events (see **Figures 3a**, **3b** and **3c**, respectively). The high inflows from the Mackenzie River during early July 1988 (in the order of 33,000 m^3/s) are more than twice as large as the mid-July 1993 Mackenzie flows (approximately 14,500 m^3/s), and the travel times are approximately one-half. However, the Peel River inflows were similar for the two aforementioned events, and subsequently the upper Peel travel times are very similar. The mid-August 1991 Peel River flows were substantially larger than the mid-July 1993 Peel flows, but the Mackenzie flows were similar, so there is only a one day difference at the farthest downstream node in the Peel system.

Table 1 Water Survey of Canada hydrometric stations in the Mackenzie Delta

Station location	Station Name	WSC station
Upstream boundary	Mackenzie River at Arctic Red River	10LC014
	Peel River above Fort McPherson	10MC002
Mid-transect Aklavik to Inuvik	Peel Channel above Aklavik	10MC003
	Aklavik Channel above Schooner Channel	10MC005
	Middle Channel below Raymond Channel	10MC008
	Kalinek Channel above Oniak Channel	10LC006
	East Channel at Inuvik	10LC002
Downstream boundary	Reindeer Channel below Lewis Channel	10MC012
	Middle Channel at Langley Island	10MC013
	East Channel below Tununuk Point	10LC016

Discussion

The flow model (ONE-D) used as part of the FOSH-MC multi-channel suspended sediment model has been applied to numerous rivers throughout Canada with good results (Sydor *et al.,* 1989). The application of the ONE-D model to the Mackenzie Delta also provides good results (Jasper and Kerr, 1994). Although the average flow velocities calculated for the estimation of travel times are adequate, the assumption that these times represent suspended sediment travel times has not been tested (in the field or theoretically). The mechanics of suspended sediment transport within the various reaches, in particular the deposition, resuspension and erosion, must be investigated for several flow events to refine the understanding of time of travel of sediment particles in suspension, and sediment slugs. The activity at bifurcations and confluences must also be examined.

The measurement of flow, sediment concentrations and particle size, and related parameters are difficult in the Mackenzie River Delta due to the size and remoteness of the system, the associated costs and the accuracy of measurement and analysis. Therefore, insitu sediment measuring equipment should be used in future sampling programs to provide real-time data.

A sediment flux module has been created by Carson (1994) that can estimate suspended sediment concentrations at mid and lower Mackenzie Delta station based on flows and concentrations at the two delta inflow stations (WSC 10LC014 and 10MC002) and the East Channel at Inuvik station (10LC002), all of which are monitored continuously throughout the year. The module is a series of regression models for the different stations, using sediment and discharge data. The sediment is assumed to be travelling slug-wise downstream. It should be noted that some of the downstream samples used in the regression occurred

Table 2 Approximate sediment travel times in days from station 10LC014 to Mackenzie Delta hydrometric stations for various flow events (except * 10MC003 from 10MC002)

station	July 06, 1988	July 24, 1988	July 25 1991	July 29 1991	Aug 17 1991	Aug 26 1991	July 19 1993	Aug 17 1993	Aug 31 1993
10MC002	1.9	1.4	1.9	1.9	0.4	0.7	1.75	2.1	2.6
10LC002	1.5	1.8	[illegible]	2.0	3.1	3.4	3.5	3.0	3.6
10LC006	1.9	2.2	2.5	2.3	3.3	3.6	3.2	3.2	3.7
10MC008	1.0	1.1	1.2	1.2	1.5	1.6	1.5	[illegible]	1.7
10MC005	1.8	2.0	2.7	2.3	3.3	3.8	3.1	3.2	1.8
10MC003 *	2.4+ 1.9= 4.3	2.8+ 1.4= 4.2	3.5+ 1.9= 5.4	3.3+ 1.9= 5.2	4.1+ 0.4= 4.5	5.0+ 0.7= 5.7	4.5+ 1.75= 6.25	4.9+ 2.1= 7.0	2.5+ 2.6= 5.1
10MC009	1.8	2.1	2.2	2.1	3.6	3.2	[illegible]	2.9	4.1
10MC012	1.9	2.2	2.4	2.3	3.2	3.4	3.6	3.8	3.8
10MC013	2.0	2.4	2.6	2.5	3.8	3.8	3.4	3.5	[illegible]
10LC016	2.5	2.9	3.2	3.0	[illegible]	4.8	4	4.1	4.8

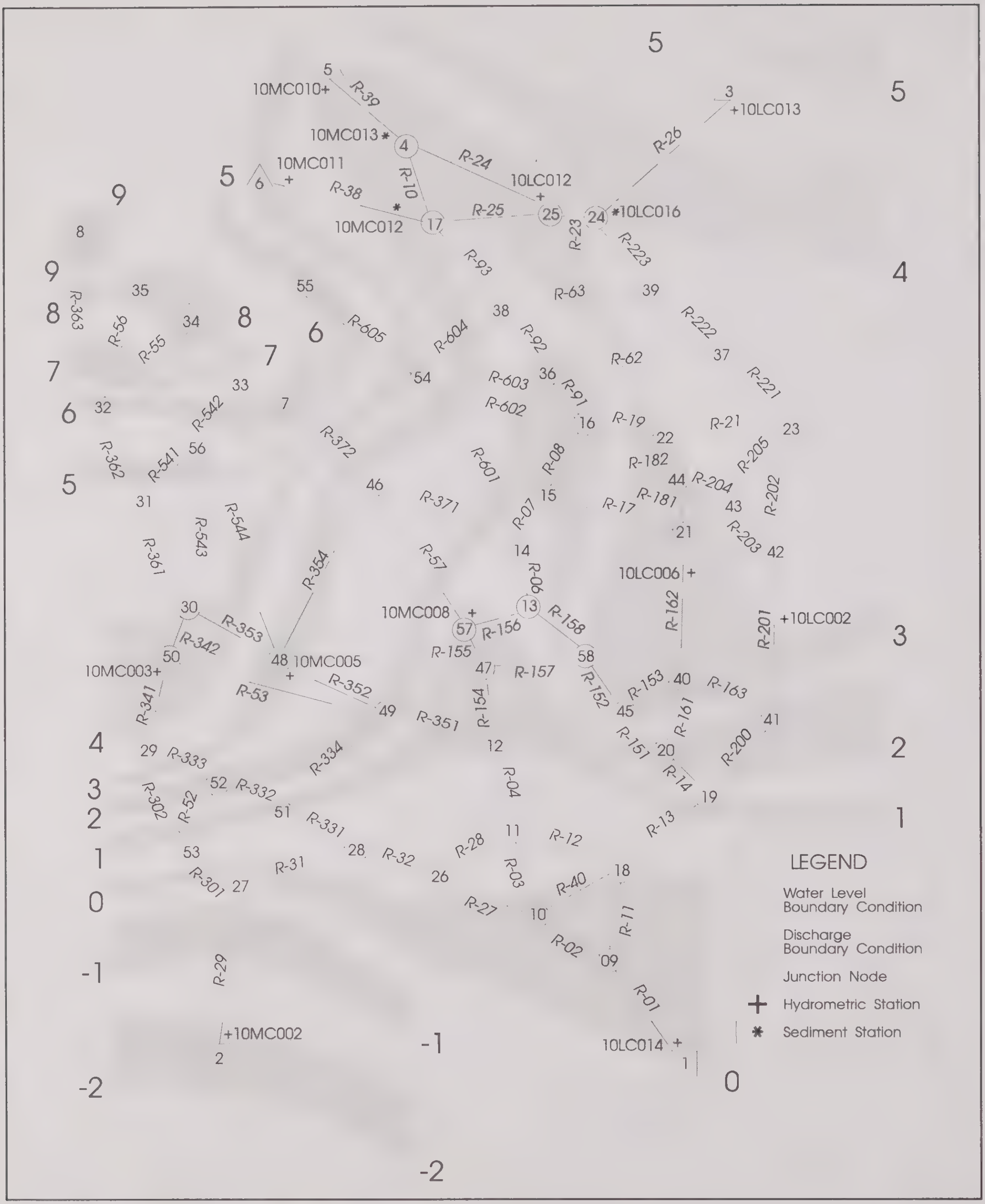

Figure 3a Calculated water and suspended sediment travel times through the Mackenzie Delta for mid July 1993 in isochrone bands of half days

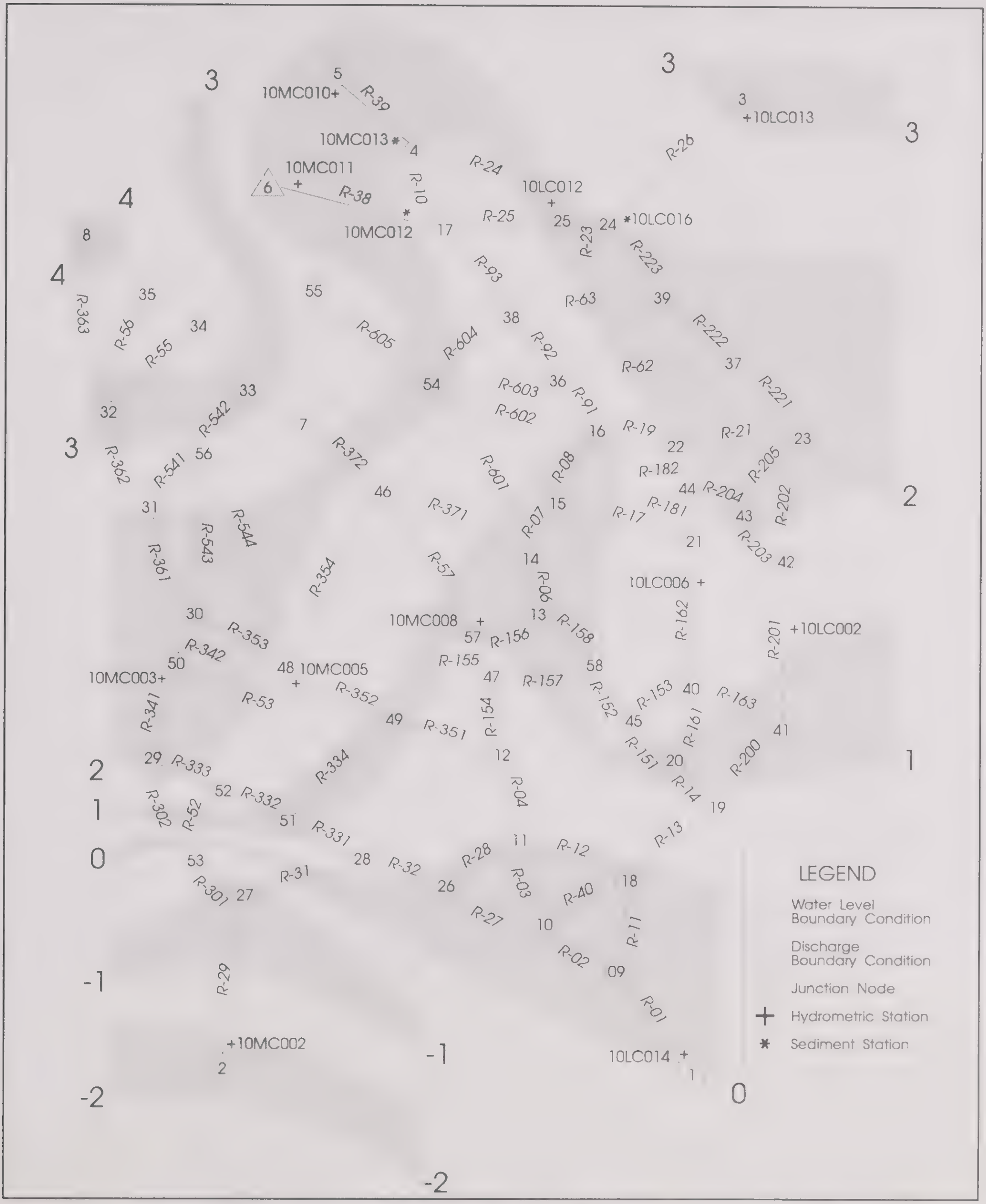

Figure 3b Calculated water and suspended sediment travel times through the Mackenzie Delta for early July 1988 in isochrone bands of half days

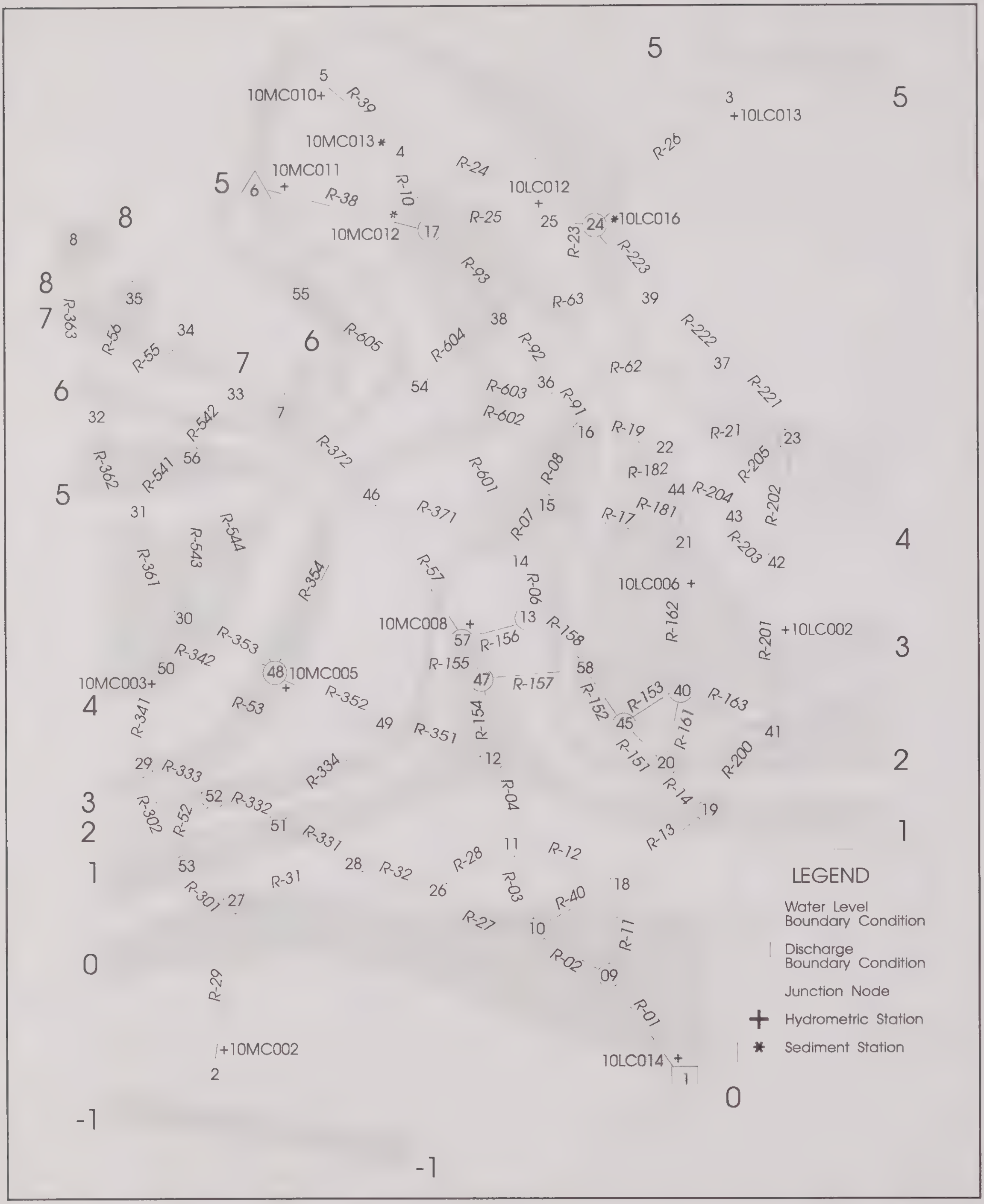

Figure 3c Calculated water and suspended sediment travel times through the Mackenzie Delta for mid August 1991 in isochrone bands of half days

prior to the upstream sampling, or more than an appropriate time after, such as a mid-delta sample being collected five days after the corresponding Mackenzie inflow sample. However, the miss-timing of sampling by several days is not important during periods of low sediment loads, since concentrations may be at the same or similar levels for weeks. Therefore, the timing of samples is likely only important for higher concentrations that usually occur as slugs. For the Mackenzie and Peel River systems such concentrations are greater than 500 mg/L, since concentrations are usually maintained at 200 to 300 mg/L throughout the open water season.

Conclusions and Recommendations

Suspended sediment travel times are dependent on flows in both the Mackenzie and Peel River systems, however the Mackenzie is obviously more important. The times can vary by more than a factor of two. Sediment sampling should consider upstream flow conditions and travel time estimates to better correlate the flow and suspended sediment relationships between sampling stations.

The use of average flow velocities as suspended sediment travel time estimates is a valid approximation, as no other method exists, however, this approximation should be further investigated. The use of flow-weighted travel time averages is another valid initial assumption, but nodal activity and nodal modelling would be useful to improve the calculation accuracy.

If the sediment travel time assumption can be improved and the FOSH-MC model were to be applied to other multi-channel regimes such as the Slave River Delta (and the Mackenzie mainstem-Liard system), the impact of various climate change scenarios on sediment transport could be investigated.

Acknowledgements

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Passive Microwave Radiometry of Snow in Mackenzie River Basin and Northwest Territories

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Abstract

A retrieval algorithm that assumes the total microwave response as the sum of responses from a composite surface has been applied to produce the snow map of Mackenzie and Northwest Territories. On the basis of five years of intensive snow surveys conducted at the McMaster Basin near Resolute Bay, and a snow survey conducted by the Hay River City near Hay River, it was found that this algorithm gives more accurate estimates of the snow than other algorithms and conventional snow measurements. However, it seems that none of the algorithms developed so far is consistent enough for operational use, unless snowpack parameters and cloud covers are accounted for in an algorithm, or unless the algorithm is applied in a relatively cloud free day.

Introduction

This study deals with the snow of Northwest Territories (NWT) and the part of Mackenzie River Basin located within the NWT. Besides NWT, the Mackenzie River Basin also occupies British Columbia, Alberta, and Saskatchewan provinces of Canada. About half of the annual precipitation in NWT falls as snow and so it is important to know the amount of snow on ground. The NWT Power Corporation uses information about the amount of snow to plan the operation of the Snare and Taltson power stations. The Yellowknife Office of Environment Canada uses corrected and uncorrected precipitation data, ungauged inflow and outflow, and lake levels to analyze the water balance of Great Slave and Great Bear Lakes (Kerr, 1996). Given that only about ten precipitation stations are available for each lake, precipitation data are highly variable spatially, and snow gauges often suffer from undercatch problems, we will expect achieving a more accurate lake water balance if in addition to those data, we also know the amount of snow on the watersheds draining to these lakes.

In NWT, snow melts in a relatively short time of spring, producing high flows under ice-jammed conditions in the Mackenzie River, which at times can be life threatening. Every year during spring, the potential floodings of the Mackenzie River due to spring snowmelt and ice jam conditions are closely monitored so that if necessary, an emergency evacuation of communities located within the flood-prone zones can be executed speedily.

Even though majority of about fifty sites where Indian and Northern Affairs Canada collects 10-point snow course data several times per year are located near Great Slave Lake and the Mackenzie River Corridor, ground measurements alone cannot provide us a representative picture of the snow distribution of the Mackenzie. As point measurements, snow course data are not expected to represent the areal distribution of snow which is highly variable spatially, i.e., results obtained from several intensive snow surveys conducted at McMaster River Basin show that the coefficient of variation of snow depth is either close to one or even exceeds one in some instances (Gan, 1996). Similarly, precipitation data may not be representative even at point scales because snow gauges, due to wind effects, often suffer from undercatch problems (Goodison, 1981).

In view of the size of Mackenzie Basin, its remoteness, and the cost of ground measurements of snow, the only feasible way to estimate the amount of snow of Mackenzie is via satellite data. This paper focuses on the retrieval of snow of Mackenzie using passive microwave, landcover, air temperature, and snow course data. Details of the areal distribution of snow in NWT were only made available for the first time via the use of SMMR data several years ago (Latham, 1991).

Passive Microwave Radiometry of Snow

Research into the use of passive microwave radiometry on snow hydrology has flourished in the last 15 years. Before to 1987, spaceborne microwave data were acquired by the Scanning Multichannel Microwave Radiometer (SMMR) of the Nimbus-7 satellite. After 1987, such data were acquired by the Special Sensor Microwave/ Imager (SSM/I) on the Defense Meteorological Satellite Program (DMSP) satellite. Spaceborne passive microwave data measured are often of frequencies ranging from 6.6 GHz to 85 GHz.

The microwave radiation thermally emitted by an object is measured in terms of brightness temperature (°K), which is related to the physical temperature of the object. On a snow-covered terrain, the microwave emitted by the underlying ground surface is scattered by randomly spaced

snow particles in all directions, particularly for microwave of high frequencies, 15 GHz and above. This scattering effect increases with an increase in snow depth, snow water equivalent (SWE) or snow grain size. Therefore, the amount of radiation a microwave radiometer or sensor receives decreases with snow depth or snow grain size. In essence, this forms the physical basis of passive microwave application in snow hydrology.

Because microwave can penetrate clouds, precipitation and snowpacks up to about a meter deep (if the frequency is 37 GHz or higher), it has clear advantages over electromagnetic waves in the visible and infrared-red range. However, it suffers from poor resolution. In addition, because water responds to an applied electromagnetic wave much more strongly than ice, e.g., water has a much larger dielectric constant, a slight melting will cause a strong microwave response. This phenomenon can be used to detect the onset of melting but it also complicates the use of microwave to estimate the amount of snow on ground. Therefore, passive microwave radiometry is mainly limited to dry snow applications only. Microwave emissions by cloud covers, which also reflect back the microwave emitted by snow-covered grounds, and microwave emissions of vegetation are other factors that complicate the use of passive microwave data in snow hydrology.

At this stage, research on developing operational algorithms for retrieving NWT's snow information from satellite data are still ongoing. Many algorithms based on multiple-stepwise and nonlinear regression techniques have been tested, i.e., Chang et al. (1987), Hallikainen (1989), and Goodison et al.(1990), etc. So far it has been found that several variations of an algorithm that assumes the sum of microwave responses from a composite surface (Eq. 1) is more promising than other algorithms (Gan, 1996). Eq. 1 shown below represents one of the several variations tested at Mackenzie.

$$SWE = K_1(AREA_{Tundra})\,(T_{H18} - T_{H37}) + K_2(AREA_{Trans})\,(T_{H18} - T_{H37}) + K_3(AREA_{Water})\,(Temp+273) + (AREA_{Conif} + AREA_{Decid} + AREA_{Mixed})\,(K_4(Temp+273) + K_5(T_{H18} - T_{H37})) + K_6 \qquad (1)$$

where $AREA_{Tundra}$, $AREA_{Trans}$, $AREA_{Water}$, $AREA_{Conif}$, $AREA_{Decid}$ and $AREA_{Mixed}$ are percent areas of tundra, transitional, water bodies, coniferous, deciduous, and mixed wood forests within each footprint respectively; T_{H18} and T_{H37} are horizontally polarized brightness temperature at 18 and 37 GHz respectively; and K_1 to K_6 are parameters calibrated through a multivariate regression model. Eq. (1) is similar to Hallikainen's algorithm (1989) except it assumes that microwave emissions from frozen water bodies are related to air temperature, and from forest covers is a weighted sum of air temperature and the difference of T_{H18} and T_{H37}. Eq. (1) is better probably because passive microwave footprints, or pixels, have coarse resolutions, between 25 and 30 km, and within each footprint there could be a mixture of surface types. Because each surface type has different dielectric properties, the total microwave emission from each footprint probably depends on the sum of responses from the surface types within the footprint.

The compositions of surface types for the Mackenzie are based on the landcover data that consist of the percentage of forest and water cover. These landcover data were originally prepared through the classification of National Oceanic and Atmospheric Administration NOAA-AVHRR satellite images by the Manitoba Remote Sensing Center. The original ten land cover classes were imported into a Canadian geographic information system called SPANS at a pixel size of 1.2 km. Using SPANS, it was then reclassified into 6 classes at a 30 km resolution to match that of satellite data. The 6 classes are coniferous forest, deciduous forest, mixed wood forest, transitional, tundra and water bodies, denoted as $AREA_{conif}$, $AREA_{decid}$, etc. in Eq. 1.

Air Temperature Model

The algorithm just described also require the use of air temperature to estimate the microwave emissions from vegetation and frozen bodies. As most parts of Mackenzie or NWT are not gauged for air temperature, a simple time series, autoregressive order-one model (Eq. 2) for estimating weekly maximum temperature of Mackenzie and NWT was built to estimate the air temperature needed.

$$(Temp_{i,\tau} - \mu_{i,\tau}) = \rho_{ik,\tau}(Temp_{k,\tau} - \mu_{k,\tau}) + \sigma_{i,\tau}\sqrt{(1-\rho_{ik,\tau}2)}\,W_{i,\tau} \qquad (2)$$

Equation (2) is a periodic, "space-lag" Markov or AR(1) for week τ where $Temp_{i,\tau}$, temperature at an **ungaged** site **i**, is estimated from $Temp_{k,\tau}$, temperature at **gauged** site **k**. In Eq. (2), $W_{i,\tau}$ is a random number of Normal (0,1) distribution, and $\mu_{i,\tau}$, $\sigma_{i,\tau}$ and $\rho_{i,\tau}$ are mean, standard deviation and correlation coefficient of site i during week τ respectively. Equation (2) is only applicable because the winter temperature data of NWT satisfies the normality assumption, and the model parameters, $\mu_{i,\tau}$, $\rho_{i,\tau}$ and $\sigma_{i,\tau}$ were estimated from 30 long-term climatic stations of Atmospheric Environment Service. Model parameters such as cross-correlation coefficient $\rho_{ik,\tau}$ was estimated from an arc-distance bivariate model and mean $\mu_{i,t}$ from a latitude-polynomial model. Tests show that AR(1) can more or

less preserve the mean temperature of five independent test sites located along the Mackenzie Corridor and five test sites located at the high Arctic. Full details of the model are presented in Gan (1995).

Results

The assessment of the accuracy of such snow maps (see an example in **Figure 1**) is difficult. As a preliminary effort, a research site near Resolute Bay, the McMaster River Basin (Lat. 74°45'N, Long. 94°50'W), has been selected to assess the accuracy of the algorithm at the high Arctic. As a tundra, the site is free from the complication of microwave emissions from vegetation and so the chance of success is higher. On the basis of the mean SWE derived through five years of intensive snow surveys conducted in the McMaster River Basin, it was found that the SWE for Resolute Bay estimated from an algorithm similar to Eq. 1 are more accurate than the standard 10-point snow course data or the weather office snowfall measurements (Gan, 1996).

In a separate snow survey conducted by a crew of the Hay River City on March 15, 1992, it was found that the snow water equivalents (SWE) estimated using Eq. (1) at 3 sites, which are all southwest of the Hay River City and within the Mackenzie Basin, were 96 mm, 92 mm, and 84 mm respectively, while averaged point measurements taken in these three sites were about 120 mm (see **Table 1**). According to an algorithm which PhD Associates directly modified for NWT from Goodison et al. (1990)'s algorithm built for Saskatchewan, the estimated SWE at the

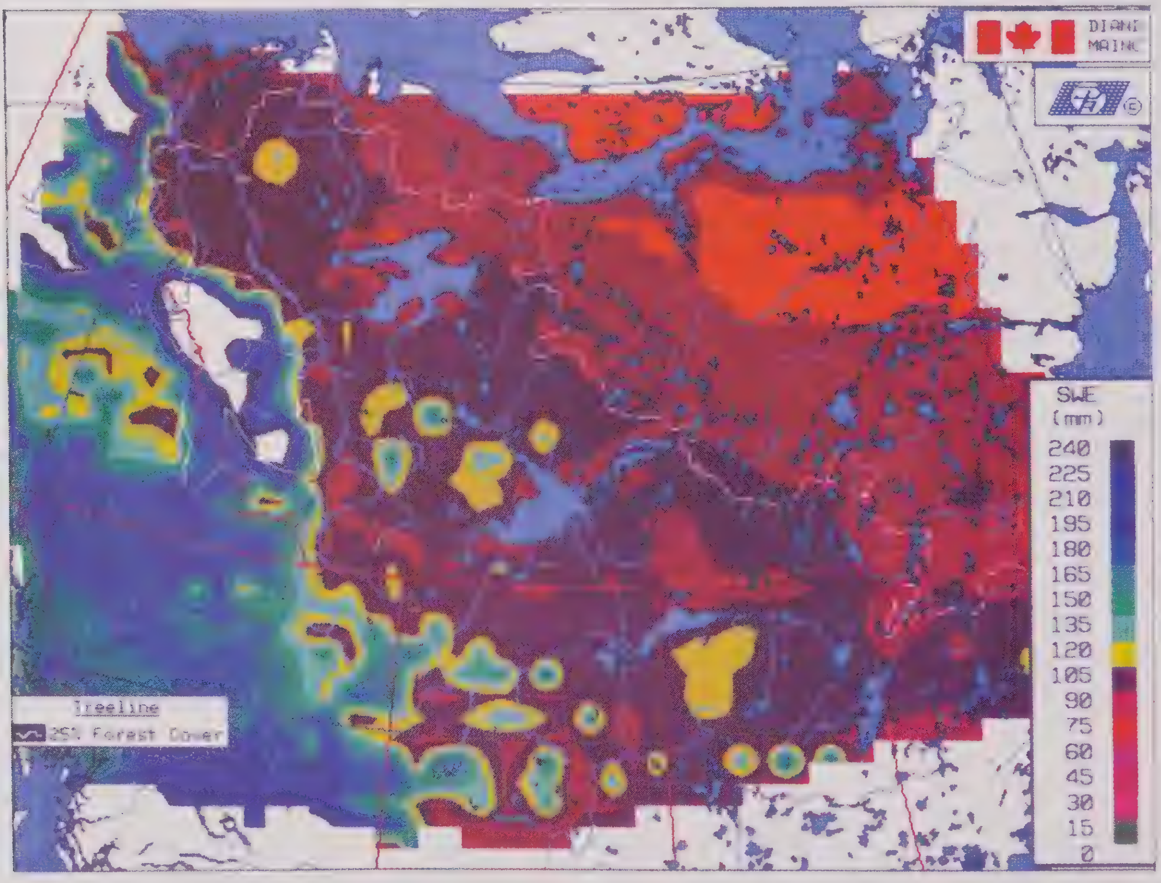

Figure 1. A map showing the distribution of snow water equivalent (mm) in the Northwest Territories (NWT). This map was derived via several closely related retrieval algorithms (one of which was Eq. 1), the passive microwave image of SSM/I at 19 and 37 GHz of horizontal polarization dated March 29, 1988, landcover data and air temperature of NWT, which were interpolated using about 30 climatic stations of Atmospheric Environment Service and Eq. 2.

Table 1. Comparison of snow water equivalent estimated from two microwave retrieval algorithms and from ground measurements near Hay River.

Site	Approximate Location	Snow Water Equivalent (mm) Observed	Equation (1)	An algorithm modified from Goodison *et al.* (1990)
Farm Road	60°N 116.7°W	120	96	61
Bistcho Road	59.4°N 117.1°W	120	92	43
Zama Road	59.1°N 117.6°W	120	84	33

three sites were only 61 mm, 43 mm and 33 mm respectively. Since the measurements taken were not quite as extensive as the snow surveys conducted at the McMaster River Basin of Resolute Bay, it may be difficult to decide whether the observed SWE of 120 mm was representative of the snow present in that three sites on that day. However, if 120 mm was a representative figure, then Eq. (1) under predicted the snow by about 20% but it was still much better than the modified algorithm of Goodison et al. (1990).

Although preliminary, the results are encouraging. However, apparently the results also indicate that annual variations in the snowpack properties and atmospheric conditions such as cloud covers should be incorporated into such retrieval algorithms for them to be fully operational. It is also likely results obtained from these algorithms will be more reliable on a relatively clear than a cloudy day because clouds add complications by emitting microwave and by reflecting microwave emitted from snow-covered surfaces back to the ground.

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LAND

Ground Warming Hot Spot in the Canadian Prairie Provinces and its Relationship to Surface Air Warming

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Introduction

The results of modelling of precise temperature logs made to depths of up to 300 m in 80 wells in the Canadian Prairie Provinces show evidence of annual warming of ground surface temperature (GST) over the past half century of 2.1 K with a standard deviation of 0.9 K. Annual surface air temperature (SAT) warming in this region for the same period, as derived from historical climatological records, has been 1.5 K with a standard deviation of 0.4 K. The difference between GST and SAT warming has been close to 40% in the boreal forest ecozone and less than 10% in the prarie grassland ecozone to the south.

It is interpreted that a large portion of the difference is the result of forest harvesting, increased forest fire activity, conversion of land to agricultural crop and grazing systems, and landscape changes due to petroleum exploration. Additional energy absorbed by the ground in the northern boreal forest area has significant impact on the overall energy balance at the earth's surface. For a subregion consisting of the province of Alberta and southwestern Saskatchewan, approximately 10^{21} J of heat has been absorbed by the ground, mostly an the latter half of this century.

Temperature-Depth Profiles

Climate-induced variations in surface air temperature at the ground level propagate downwards following the laws of conduction in the absence of significant water movement. A profile of temperature with depth has been shown to contain information of past surface air temperature variations (Lachenbruch and Marshall, 1986). The relationship between SAT changes (recorded at screen level 1.5 m above the ground) and GST changes below the surface is complex. The effects of snow, ice, and surface water can be significant (Lewis and Wang, 1992; Outcalt, 1994; Taylor, 1995). However, a large part of the high frequency random distortion influencing surface air temperature variation is cut off by the earth, which acts as a low pass filter. Long-term processes such as land clearing, vegetation changes, and surface and subsurface moisture changes, some of which are anthropogenic, will have an effect on subsurface temperatures with depth.

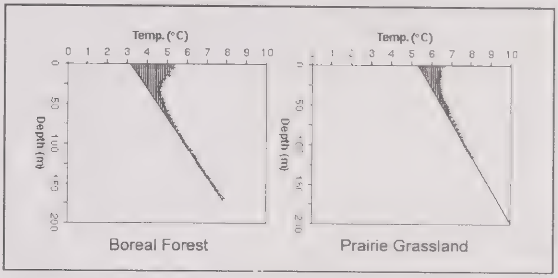

Figure 1. Typical disturbances for northern and southern Alberta.

The temperature logging in shallow wells (150 m +/ - 50 m) indicate ground surface warming in the 1.0 K to 3.5 K range. Examples from Alberta can be seen in **Figure 1**. The surface warming causes an observable anomalous curvature in temperature- depth profiles in the top 70 - 110 m indicating that the accelerated warming pertains to the second half of this century. Temperature profile with depth represents the response of the ground to recent warming of the mean annual surface temperature from a previous long-term value obtained from the extrapolation of the linear portion of the temperature profile with depth to the surface (Lachenbruch and Marshall, 1986).

Study Area

Temperature measurements have been made in some 80 wells at sites in the Western Canadian Sedimentary Basin. Most of the data were obtained from wells in Alberta (Majorowicz 1993; Majorowicz and Skinner 1996), with additional wells in the southern parts of the Northwest Territories and Yukon (Taylor et al., 1982), as well as wells in Saskatchewan and Manitoba (Majorowicz and Skinner 1996; Beltrami et al., 1982). The linear "ramp" function fitting of the ground temperature warming history for this century was applied to model dT disturbance of the temperature-depth profiles for the 80 wells shown in **Figure 2**. Since most of the GST warming in the Prairie

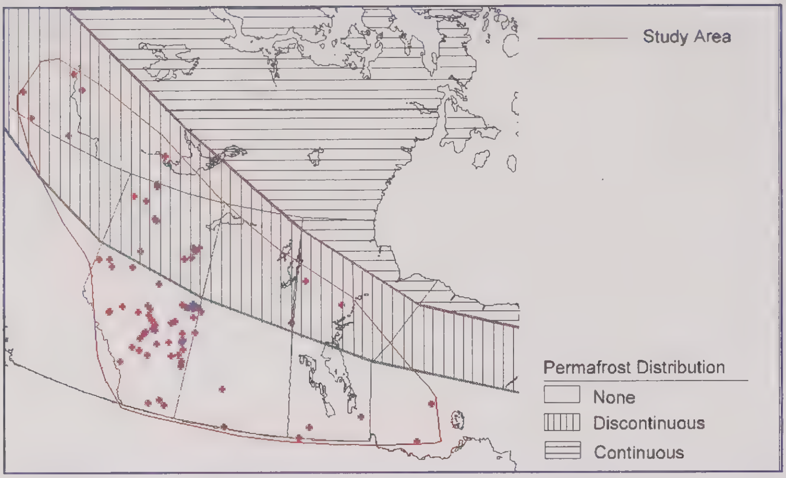

Figure 2. Western Canadian well sites and permafrost distribution.

province wells has been in the past four decades, as found from modelling and statistical analysis of the data, warming magnitudes for the period 1950 to 1990 were used in contouring and then compared with the magnitudes of the surface air temperature warming for the same period.

Ground Warming and Air Warming Comparison

Contour maps were made of well-estimated GST warming and SAT warming. The irregularly spaced GST well data were transformed to a regular grid by the kriging method and then contoured using SPANS GIS. As shown in **Figure 3**, GST warming varies from less than 1.0 K in the Foothills of the Rocky Mountains in southern Alberta to values exceeding 3.0 K in northern Alberta and southern Saskatchewan. The magnitude of the GST warming is, in general, larger in the boreal forest ecozone than for the southern prairie grassland ecozone.

Station data from Environment Canada's Historical Canadian Climate Database (HCCD) were used to map mean annual SAT change from 1950 to 1990. The HCCD was assembled to provide a collection of historical datasets that have been tested for homogeneity and adjusted where necessary to ensure regional representativeness. Best-fit linear trends were calculated for individual HCCD annual time series for the 1950 to 1990 period. The irregularly spaced station data were transformed to a regular grid by the kriging method then contoured using SPANS GIS. As shown in **Figure 4**, the largest increase in mean annual SAT was greater than 1.6 K in central Alberta and Saskatchewan with peaks over the Peace River and Cold Lake areas. Smaller increases of less than 1.0 K occurred in the extreme southern and northern parts of the study area.

Subregion Analysis

The area of about 720,000 km^2, consisting of the province of Alberta and southwestern Saskatchewan, with the largest amount of well temperature data, extends from the southern margins of permafrost in the NWT and Alberta to the Canada-U.S.A. border and samples two major ecozones, the boreal forest in the north and the prairie grassland in the south. **Figure 5** shows the map of annual GST minus annual SAT. The larger magnitude of GST warm-

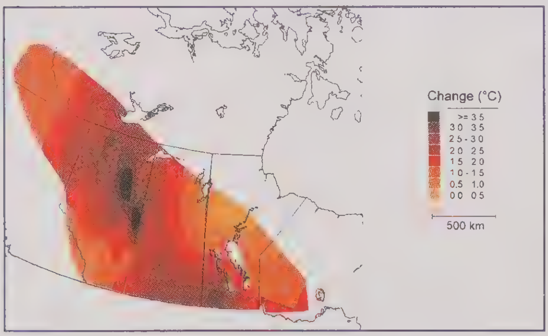

Figure 3. Annual ground surface temperature (GST) change 1950 - 1990.

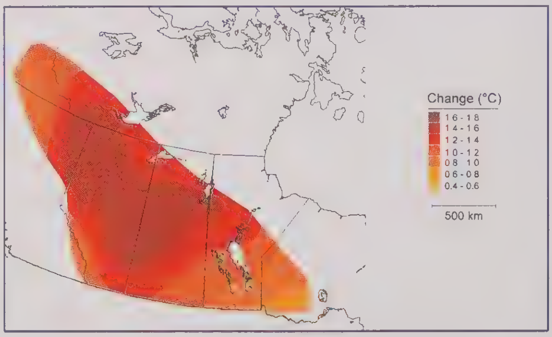

Figure 4. Annual surface air temperature (SAT) change 1950 - 1990.

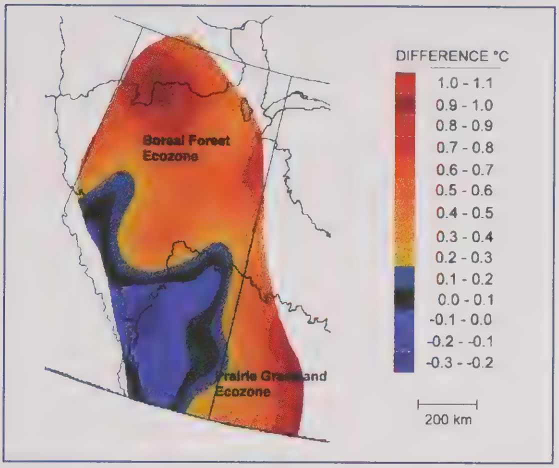

Figure 5. Annual GST change minus annual SAT change 1950 - 1990.

ing in the northern part of this area is clearly evident while GST and SAT differences are smaller in the south and southwestern areas of this subregion.

A spatial comparison was made between SAT and GST warming in this region. A statistically significant spatial correlation exists ($r = 0.75$) between identical grid samples extracted from the two 1950 - 1990 warming maps. Also, a GIS area cross tabulation was performed through the intersection of the classes of the two warming maps with a resulting contingency coefficient of $C=0.805$. While similar spatial patterns of warming have occurred, the GST warming is approximately 40% larger than the SAT warming in the boreal forest ecozone.

In this area of study, some of the natural forest of the boreal forest ecozone has been converted to agricultural crop and grazing systems (150,000 km^2). Some of the area has been harvested for wood fibre (5,000 km^2). Extensive forest fires, many over 100 km2 in size, have occurred in this region between 55° N and 62° N during the early 1950s and especially between 1979 and 1981. The total area burned in the last two decades is 130,000 km^2. To the north of this subregion, in the southern NWT, near Fort Simpson and Fort Smith, approximately 100,000 km^2 has been burned.

Figure 6 shows frequency histograms of SAT and GST change for locations in the boreal forest ecozone north of 53.5° N and the prairie grassland ecozone south of 53.5° N for the period 1950 to 1990. The average magnitude of the GST warming for the entire region is 2.1 K (S.D. = 0.9 K) based on 56 well sites in this subregion. Statistical analysis shows that in the northern boreal ecozone ground warming is high (Average = 2.5 K, S.D. = 0.9 K). The southern region (prairie grassland ecozone) is characterized by smaller mean GST warming (Average = 1.6 K, S.D. = 0.6 K). SAT frequency histograms from HCCD instrumental records for the second half of this century show close agreement between the northern and southern ecozones with the identical average value of 1.5 K. The difference between GST and SAT warming is 0.6 K for the entire area (28% difference), 1.0 K for the northern area (40% difference), and 0.1 K for the southern area (6% difference). The highest GST warming is observed for wells in north-central and northeastern Alberta in the boreal forest ecozone. These are areas of petroleum exploration and related forestry and agricultural land changes which took place mostly since the 1960s.

Discussion

We have integrated the heat energy absorbed in the upper 100 m of the subsurface due to ground surface warming in this century for the Alberta subregion. It is calculated to be 130 x 10^{18} J. This is the total energy related to climatic surface warming plus additional heat energy due to changes to the surface radiation balance due to landscape changes. The amount of energy stored in the ground due to surface landscape changes in this century alone is calculated to be 30 x 10^{18} J. This additional amount of energy is stored in the subsurface, and is changing the overall energy balance. We estimate the total amount of energy absorbed by the subsurface in this century in Canada to be in the order of 10^{21} J. Most of the landscape changes took

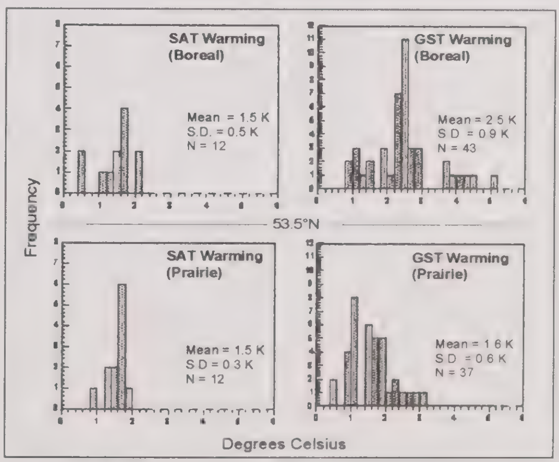

Figure 6. Histograms of GST and SAT warming in Alberta subregion.

place in the boreal forest ecozone where the largest difference between GST and SAT warming is observed. The magnitude of the additional heat storage in the subsurface due to landscape changes is estimated to be large enough to explain a major part of the observed difference.

The impact of the blanketing effect upon GST change is calculated to be of lesser magnitude since no significant change in overall precipitation has been observed for the Prairie Provinces (Mekis and Hogg, 1995). The hypothesis that warming of the ground may be associated with a trend to increased snow cover is at odds with the observation of a slight decrease in total snowfall by 7.1 mm per decade in the Northwestern boreal forest and 11 mm per decade in the Prairies for the period 1950 to 1994 (Mekis and Hogg, 1995). Decreasing continental snow cover over the past few decades has likely caused a greater amount of solar radiation to be absorbed by the ground surface. This effect would be offsetting the effects of deeper freeze penetration due to a decrease in insulation, resulting in more extensive ground warming.

Summary

Future clearing of the forests will cause ever increasing areas of the landscape (approximately 1% of the boreal forest will be harvested each year) to exhibit increased soil surface warming. This continues to be superimposed on a steady increase in mean annual surface air temperature over the past few decades. These anomalous conditions of accelerated ground warming will influence the northward movement of the of the 0°C isotherm and thus the southern permafrost boundary (**Figure 2**). The northward movement of the southern boundary of permafrost has already been observed by independent research (Kwong and Gan, 1994). The regions which were discontinuous - scattered permafrost during studies in the 1960s (Brown, 1983; Englefield, 1995) with GST in the 0°C to -5°C range are warmer by at least 1-2 K where SAT warming has occurred and 3-4 K in some cases where SAT warming is superimposed on the warming caused by landscape changes. In all of these areas, heat energy flux per unit area has been increasing.

The large magnitude warming observed in the Canadian Prairie Provinces in recent decades is only a part of the large scale regional warming taking place in the northern parts of North America. GST warming found from well temperatures in Alaska (Lachenbruch et al., 1982, 1988) suggests that the warming extends from western Canada northward. Contrary to this, GST cooling has been reported for the southern shore of Hudson Strait in recent decades (Allard et al., 1994).

In conclusion, the evidence proves that western Canada GST warming is much larger than SAT warming. It is hypothesized that a large portion of that warming is a result of accelerating natural and anthropogenic changes to the landscape which lowers the albedo and increases heat flow into the ground. If the rate of climatic warming and anthropogenic change to the land surface continues, the southern boundary of the discontinuous permafrost will move northward at a faster rate than predicted from instrumental SAT warming data alone.

The interactions between accelerated ground warming and large-scale climatic processes and climatic variability requires further study. Current research is focusing on deeper wells (>300 m) in order to reconstruct surface climatic conditions prior to the instrumental record.

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Permafrost in the Mackenzie Basin, its influence on land-altering processes, and its relationship to climate change

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Permafrost underlies approximately two-thirds of the Mackenzie River drainage basin. Strictly speaking, permafrost is a thermal condition of the ground, whereby the temperature remains at or below 0°C throughout the year. If water is present it will likely be frozen but not necessarily. The freezing point of water can be lowered due to salinity or the attraction of water molecules to electrically charged mineral particles. Nevertheless, by a few degrees below 0°C, most of the water content of any material will be frozen. The presence of ice-rich permafrost is most strikingly apparent when this ice melts, resulting in collapse of the ground surface, loss of bearing strength of the ground, and shear strength failure leading to landslides and thaw flows.

Only within that part of the Mackenzie Basin between Great Slave Lake and the Beaufort Sea does permafrost become generally thick enough to require consideration in engineering design and construction (see Figure 1 for a general indication of permafrost distribution). In the Fort Simpson area, permafrost may reach thicknesses of up to 20 m and underlies roughly 30% of the terrain. Its presence is dependant on forest and wetland type. Spruce forests are most effective at intercepting snowfall and reducing the depth of snow on the ground, thus favouring colder ground temperatures. Bogs are a type of wetland that may be elevated slightly and can dry out in summer, thus maximizing the insulating properties of the living vegetation mat during the warmest part of the year. In the Norman Wells area, thicknesses may reach 60 m and about 80% of the terrain is underlain by permafrost. At Inuvik, permafrost is virtually ubiquitous and thicknesses in excess of 100 m are common. The exception in the north is the Mackenzie Delta where permafrost is generally less than 100 m thick because of warmer ground temperatures favoured by dense, snow-trapping, willow growth and the warming effect of migrating delta channels (Judge et al., 1987).

Permafrost is most closely related to wetland type at its southern fringe in the northern prairie provinces. Here, permafrost up to a few metres thick generally underlies peat bogs whereas fens, characterized by a higher watertable, are unfrozen. In this area, permafrost underlying bogs has been disappearing in response to warming of between 1 and 2°C in average annual air temperature since the end of the Little Ice Age, about 200 years ago (Halsey et al.,

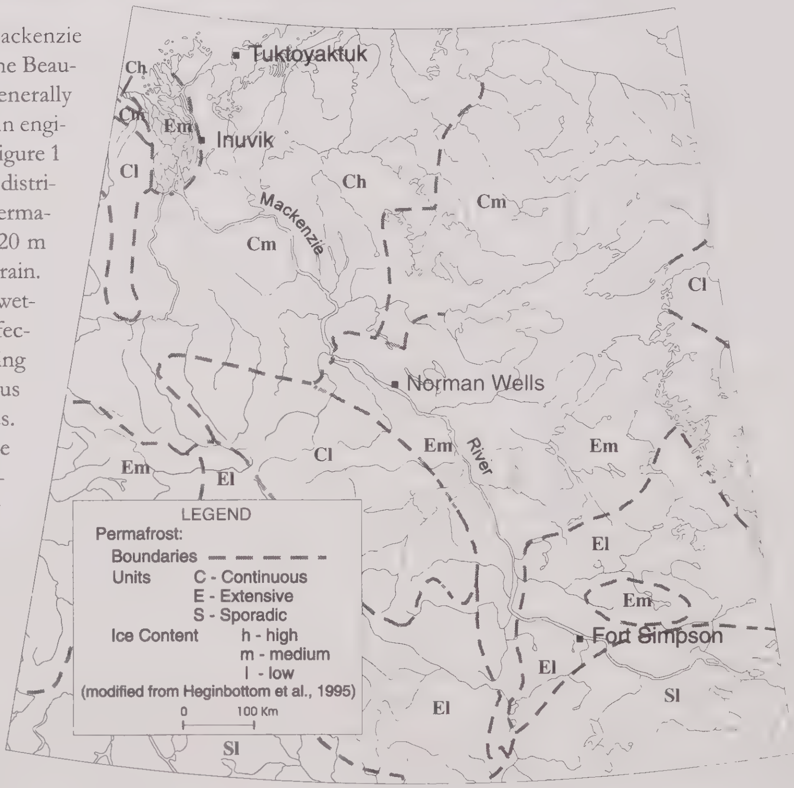


Figure 1. Permafrost distribution and generalized ground ice content in the Mackenzie Valley.

1995). As a result, bogs are collapsing as ice melts, resulting in internal depressed areas referred to as lawns or complete incorporation into fens if the bogs are isolated. However, permafrost presently exists in areas where average annual air temperatures are warmer than those originally required to initiate permafrost growth. This is possible because of insulating vegetation which became established since the inception of permafrost. Further north, permafrost is too thick and too cold to be significantly affected by the same amount of warming.

Climate change in the Mackenzie Valley is evident from instrumental records that for a few locations extend back to the 1890's. On this basis, mean annual temperatures have increased 1.7°C during the last century (Environment Canada, 1995). It must be kept in mind that this change may not be representative of the entire Mackenzie Valley because of the scarcity of data. If it were representative, this warming amounts to a northward shifting of mean annual air temperature isotherms of 100-200 km. However, permafrost has lagged in its response to such a shift because of the vegetation succession related to permafrost growth and consequent increase in insulation as noted above. Furthermore, recent climate warming is not ubiquitous in the north. The eastern Arctic shows a decrease in average annual temperature over the same time interval in which the Mackenzie region has warmed and permafrost is aggrading in areas such as northern Quebec due to local cooling (Allard et al., 1995).

Modelling that takes into account the insulating effect of vegetation and snow cover has been used to predict the response of permafrost to continued climate warming. With sufficient detail in the distribution of vegetation and thermal properties of peat and near-surface glacial sediments, a predicted permafrost distribution can be mapped. For a 40 km square area surrounding Fort Simpson, permafrost is predicted to eventually almost disappear under a 2°C increase in average annual air temperature (Wright, 1995). For the same increase at Norman Wells, permafrost would ultimately be reduced to about half the present area. It must be kept in mind that these are equilibrium predictions, whereby permafrost has had enough time to come into equilibrium with an instantaneously increased average annual temperature. Therefore the models give no information on how quickly these changes would take place or on the severity of impacts which may be associated with melting ground ice.

Modelling was also carried out for specific locations in the Mackenzie Valley, based on borehole records of sediment type and ice content (Geo-Engineering (M.S.T.) Ltd., 1992). With this more detailed characterization of frozen materials, it was possible to predict a response of permafrost to climate warming throughout an assumed time interval during which climate is changing. The General Circulation Model developed by the Atmospheric Environment Service predicts a 4 to 5°C increase in average annual air temperature for the Mackenzie Valley in the case of an atmospheric carbon dioxide content of double the present concentration. If it is assumed that this doubling takes place in 50 years and that the climate responds on this time scale, then an air temperature trend can be constructed. This warming over 50 years would eradicate most permafrost in the Fort Simpson area, cause substantial thinning from the top down of permafrost in the Norman Wells area, but only increase the thickness of the layer which thaws each summer (the active layer) in the Tuktoyaktuk area (Figure 2). Changes in snowfall are taken into account in the model, but both as a decrease and increase relative to current amounts because of the uncertainty on how snowfall will respond to an increase in temperature. If snow cover did decrease, then ground temperatures will remain cool because of decreased insulation in winter.

How the terrain responds to permafrost degradation is probably most dependent on the ice content of the peat and glacial sediments which dominate the surficial materials of the Mackenzie Valley. Data on moisture contents are available from the Mackenzie Valley Geotechnical Database (Lau and Lawrence, 1976), a compilation of approximately 12,000 boreholes drilled in the course of pipeline route investigations in the 1970's. Also, a log of ice contents and sediments encountered in the trench excavated for the Norman Wells to Zama, Alberta oil pipeline was recorded. Although ice contents are highly variable, this information demonstrates that they are generally related to sediment textures. Silts and clays tend to have the highest ice contents on a volume basis, with in excess of 50 % possible, but thick ice layers can be associated with sands. Therefore, glacial lake sediments (silts and clays) and fine grained tills (sediments deposited at the base of glaciers) are most likely to be ice-rich whereas fluvial sediments (sands and gravels) are least likely to contain ice in excess of the pore volume. Peat is also characterized by high ice contents and is found as the covering material on all level, poorly drained areas of the Mackenzie Valley. Because of its high ice content and organic nature, it is the most compressible material when thawed.

Melting ground ice will induce settlement of the ground surface as the water produced is expelled by compaction. The collapse which follows melting will likely be

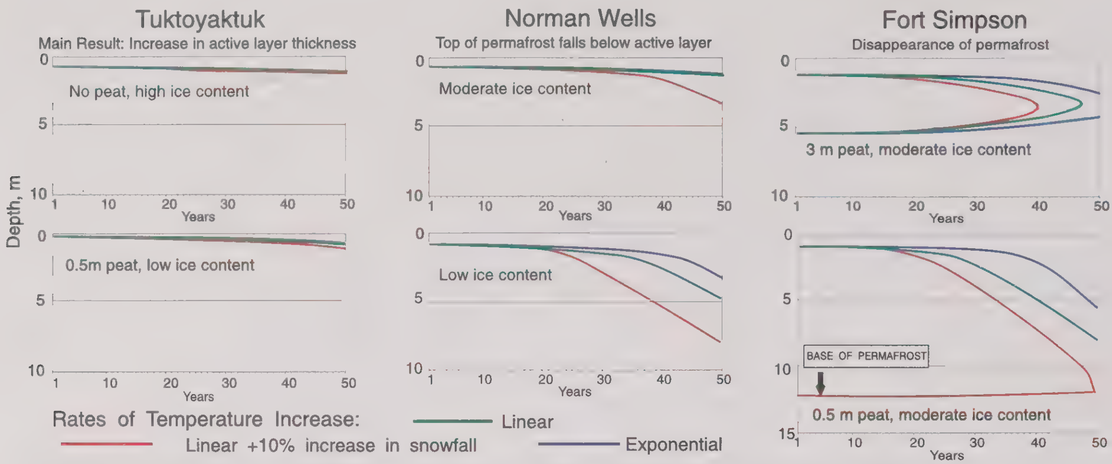


Figure 2a. The response of permafrost to an increase in mean annual air temperature of 4 to 5°C over 50 years is shown for three locations in the Mackenzie Valley. Each pair of graphs shows how differing amounts of ground ice and peat will influence the rate of permafrost response.

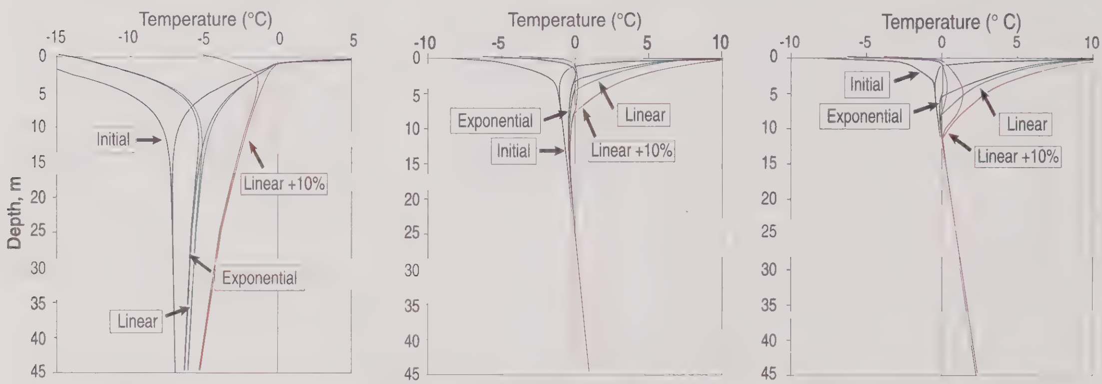


Figure 2b. Profiles of ground temperature for the above locations, showing how ground temperatures will increase depending on the rate of air temperature increase.

variable from place to place, resulting in uneven settlements of the ground surface. In lacustrine sediments and peat, ice contents can exceed 50% by volume in the first few metres below the ground surface throughout the Mackenzie Valley. If the mean annual air temperature did warm by 4 to 5°C over the next 50 years, much of the ice in these ice-rich zones as far north as Norman Wells would likely melt, producing settlements in excess of 1 m. However, compared with temperature changes since the end of the Little Ice Age, this prediction is extreme and should be considered as a worst case. Ground settlements of up to 1 m over 10 years have been observed along the right-of-way of the Norman Wells pipeline (Burgess, 1995) but this is due principally to disturbance of the ground surface vegetation mat during construction (and possibly to a number of particularly warm years over the last decade rather than general climate warming). Also, the active layer thickness is being monitored at approximately 60 sites throughout the Mackenzie Valley (Nixon and Taylor, 1994) but the maximum length of record is 4 or 5 years and this is for the sites in the Mackenzie Delta. Although most of the Mackenzie Delta sites show up to 10 cm of deepening of the maximum frost table depth below an arbitrary datum, the length of record is too short to be confident about the cause for this change. Factors related to instrument installation cannot be discounted until a longer interval of observation is available.

The other important landscape-altering process that may be affected by climate warming in a permafrost setting is landsliding. Stability of slopes is enhanced by the

strength imparted by ice bonding in frozen sediments. Any process which results in the exposure of icy sediment to thaw may induce a landslide. Thawing not only reduces cohesion but may also reduce frictional strength of the sediment if ice in excess of the sediment pore volume is present. The water produced by thaw must escape but until it does so, it carries the weight of the slope sediments, decreasing the friction between soil particles. Landslides caused by the exceedance of the cohesion of frozen glacial sediments by fluvial undercutting of river banks and by elevated pore water pressures due to thawing of ground ice are common in the Mackenzie Valley. Approximately 2,000 slides have been documented in the Mackenzie Valley, with a further 1,000 retrogressive thaw-flows identified in the Mackenzie Delta-Tuktoyaktuk Peninsula area (see companion article in this volume by Aylsworth and Duk-Rodkin).

Not enough information on the age of Mackenzie Valley landslides is available to know if the failures are related to climate warming. However, it is reasonable to expect that a direct association may exist, given that the strength of frozen ground is very temperature dependent at temperatures down to a few degrees below 0°C. Although the strength of frozen ground is difficult to determine, warming of frozen ground, even without significant thaw, may be enough to induce failure. Furthermore, the stability of steep frozen slopes in lacustrine sediments along the Mackenzie River and lower tributaries is very sensitive to the thickness of the frozen layer because of the large contribution to slope strength that this layer makes (**Figure 3**). Although thawing of the top of permafrost due to climate warming may be slow, groundwater recharging from unfrozen zones beneath lakes and flowing beneath the frozen layer may be able to transport heat to the base of permafrost and accelerate the decrease in thickness of this layer.

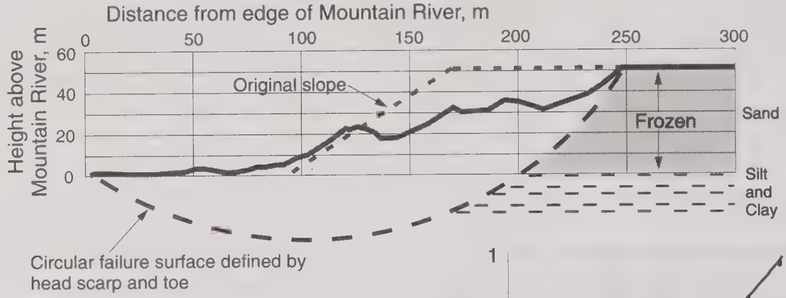
Active layer detachment slides are often associated with areas burned by forest fires. The partial or complete destruction of the insulating properties of the vegetation mat allows an increased transmission of heat into the ground, resulting in more rapid thaw. Therefore meltwater from ground ice is produced more quickly. Furthermore, the ice-rich zone that often exists at the top of permafrost may be penetrated by deeper thaw. These shallow slides may evolve into a retrogressive stage where continued uphill thawing is promoted by high ground ice content. How deeply the vegetation mat is destroyed will determine the increase in rate of thawing and maximum depth of the active layer. This, combined with the ice content, texture of the sediments, and slope angle, will determine the likelihood of an active layer failure. Predicting the likelihood of slope failure for a specific location is difficult because of the variability of ice contents and wetness of the vegetation mat which may limit burning. In a more general sense, if climate change includes warmer summers, forest fire may become more prevalent and result in an increase in the occurrence of active layer slides.

Although climate warming is capable of inducing changes in permafrost distribution and producing landscape changes, other effects are also presently active. Permafrost often terminates approximately at the margin of rivers, lakes, and oceans and is related dynamically to them. Changes in the margins of these features due to channel migration, shoreline erosion, and lake drainage will modify the local thermal conditions, causing an adjustment in the permafrost distribution. As an example, mean annual ground temperatures ranging between -2 and -8°C are found beneath bars kilometres in extent at the mouths of channels in the outer Mackenzie Delta, indicating a wide range in ages of formation from only a few 10's of years to several hundred. The distribution of permafrost beneath the Mackenzie Delta is complicated by channel migration where erosion on the cutbank side of a bend initiates permafrost thaw and sedimentation on the point bar side re-establishes permafrost growth. If the migration rate is fast enough, permafrost may extend entirely beneath a channel. Islands and bars in the Mackenzie River also migrate and probably have permafrost aprons whose shape is also dependent on migration rate.

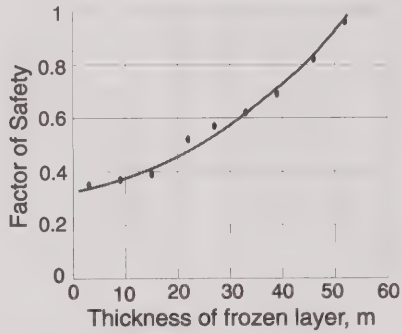
Even if the accuracy of the climate warming predicted to accompany increasing carbon dioxide is in doubt, an extension of the warming trend established since the end of the Little Ice Age is a reasonable change to expect. Several climatic fluctuations have taken place over the last 10,000 years and permafrost has responded to these. In the case of post-Little Ice Age warming, permafrost will continue to retreat but physical effects on the terrain which interfere with land use practices are unlikely until thicker, ice-rich permafrost regions along the Mackenzie Valley from Fort Simpson northward are warmed sufficiently to promote thaw. In the meantime, short term events such as particularly warm summers and fires must be included in any assessment of environmental change likely to affect permafrost. The Geological Survey of Canada is compiling a document on permafrost character, past climate change, landscape-forming processes and their relationship to climate change to be published in an atlas format. This publication is intended as a detailed summary of what is

Figure 3. A rotational slide near the mouth of Mountain River (about 90 km downstream on the Mackenzie River from Norman Wells) gives an opportunity to examine how severely climate warming may reduce slope stability. Failure took place in Glacial Lake Mackenzie sediments where frozen sands overlie unfrozen silts and clays. With a failure surface assumed to be a circular arc defined by the head scarp and the toe of the slide, the failure strength of the frozen sand can be determined.

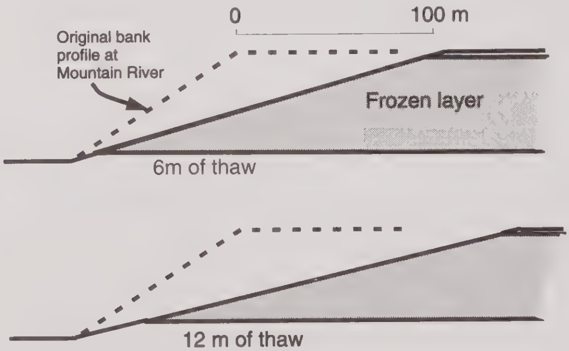
Profile of Mountain River Slide, Mackenzie Valley, N.W.T.



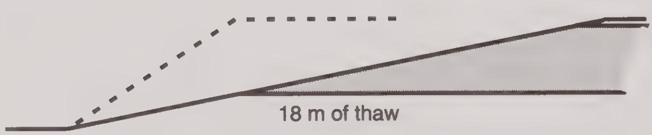
The frozen sands provide by far the greatest component of strength to these slopes. The graph shows how sensitive the factor of safety is to the thickness of this layer. The factor of safety is the ratio of the strength supporting the slope to the stresses available to shear the material. When it falls below 1, the slope is prone to failure.



Maximum Stable Slope for a Given Amount of Thaw



These profiles show the maximum slope angle that would be stable for decreasing thicknesses of the frozen layer. In this example, thawing is shown to be occurring upwards from the bottom of the frozen layer. This may happen more quickly than thawing downwards because a great deal of heat could be carried to the base of the frozen layer by groundwater flow.



known about permafrost in the Mackenzie Valley and background source for assessing the implications of climate change for permafrost distribution and behaviour.

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Landslides and Permafrost in the Mackenzie Valley

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Abstract

The Geological Survey of Canada has compiled a map and database of the distribution of three thousand landslides in the Mackenzie Valley, adjacent mountains, and Arctic coastal plain. In addition it has investigated the causes and geological controls of these landslides. Many of the landslides are related to the degradation of permafrost and ground ice; others are influenced by the control permafrost maintains on ground water movement. In permafrost terrain, many failures are induced by thermal instability, caused by proximity to warm bodies of water, abnormally warm air temperatures, extreme precipitation events, or some disruption of the insulating organic mat. Given the prevalence of permafrost and icy sediments in this region, any climate change leading to a rise in ground temperatures and degradation of permafrost will increase the frequency of landslides in the area. By identifying those areas most subject to failure today and by understanding the relationship between landslides, sediment type, and permafrost, the GSC is attempting to identify on a regional basis, those areas most likely to be susceptible to the impact of climate change in the future.

Introduction

The Geological Survey of Canada has compiled a landslide inventory, consisting of some 3400 landslides (**Fig. 1**), for the Mackenzie Valley and adjacent mountainous regions and the Mackenzie Delta and Tuktoyaktuk Peninsula regions (Aylsworth, 1992; Duk-Rodkin, 1993; Aylsworth and Egginton, 1994). Within an area of this size, a tremendous variety of topographical, geological, and thermal conditions are found. Topography ranges from flat to rolling plains, to incised plateaus and rugged mountains. Most of the valley is covered by Quaternary sediments deposited beneath glacial ice (till), in glacial lakes (lacustrine sand, silt and clay), and meltwater streams (glaciofluvial and alluvial sands and gravels). Permafrost underlies much of the region. Permafrost varies from continuous and thick (>100m) in the north to sporadic and thin (<5m) in the extreme south of the valley. Segregated ground ice is common in all fine grain

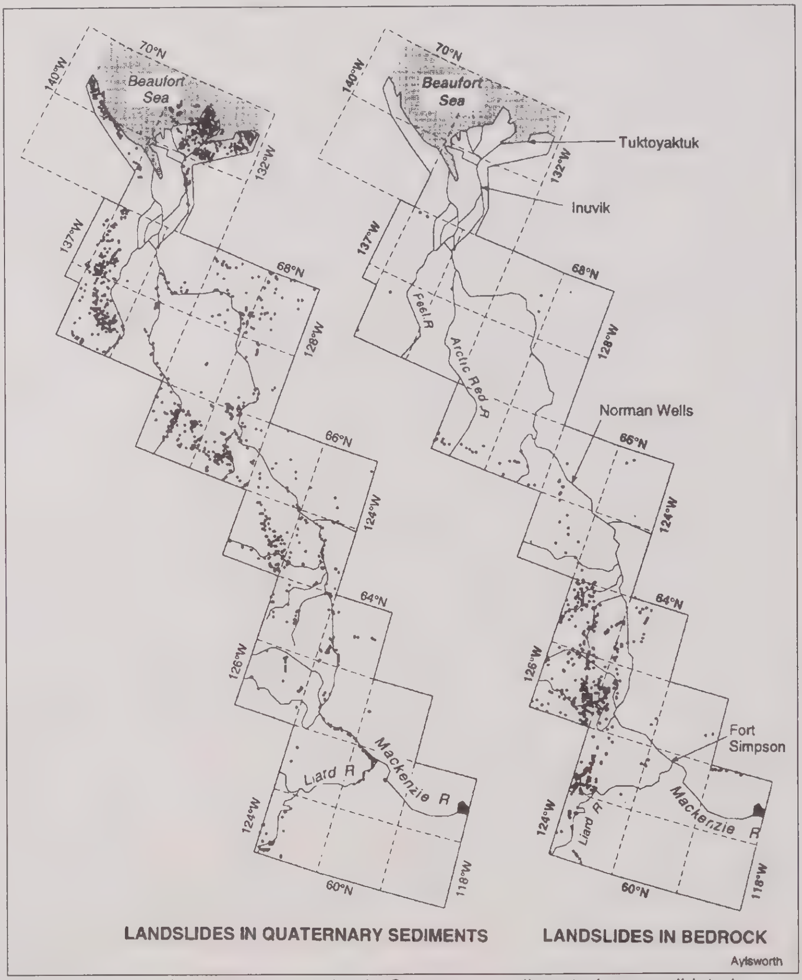

Figure 1. Map of landslides occurring in Quaternary sediments (unconsolidated sands, silts, clays, and tills). One dot on the map may represent numerous closely spaced landslides

sediments.

Because of the variety of physical conditions in the region, the types of landslides and their mechanisms of failure vary accordingly. Many of the slope failures occur in bedrock (commonly shale) and are generally not highly susceptible to climatic influence, however, many other failures are closely associated with permafrost degradation and are related to thermal or climatic factors. The following discussion is limited to these latter failures in Quaternary sediments, where, because of their softer, non-consolidated nature when thawed, ice bonding due to permafrost provides a large component of the sediment strength.

In the Mackenzie Valley and adjacent regions the major impact of landslides resulting from global warming would concern infrastructure — primarily location, design, construction, and maintenance of pipelines, roads, and bridges. River navigation might be temporarily affected in the event of a landslide dam on a river. Increased landslide activity could also impact on fisheries through possible increased siltation in streams and rivers and possible destruction of spawning beds.

Types of landslides

Landslides in permafrost terrain are characterized by two main classes, — "flows" and" slides". Flows have a fluid character, showing evidence of mobility throughout the failure. Slides, on the other hand, show evidence of more rigid movement in that components of the slide move downslope in a more or less intact manner as a block or series of blocks. Two other failure classes, "falls" and "topples" (the names are self-evident) have a minor role, particularly as a contributing factor to the development of a larger failure. Two or more mechanisms of failure may be active at the same time in an individual landslide. As a landslide develops, — and a slope movement in permafrost regions may continue either continually or cyclically for weeks, years, or even decades, one type of failure may evolve into another type.

Flows can be subdivided into shallow, active layer detachments (or skin flows), deeper retrogressive thaw flows (also commonly known as bimodal flows or ground ice slumps), and rapid debris flows.

Shallow slope failures involving detachment and downslope movement of only the active layer and vegetation mat are known collectively as active layer detachment failures. Movement may involve either sliding of a relatively intact, thawed piece of ground on the underlying frozen sediment (sometimes known as an active layer glide) or flow of water-saturated sediment (also known as a skin

Figure 2a. Retrogressive thaw flow in fine grained sediments near Tuktoyaktuk. Note massive ground ice exposed in the head scarp. GSC photo 1996-133B by J.M. Aylsworth.

Figure 2b. Landslide along a tributary of the Mackenzie River began as a shallow skin flow and has developed into a deeper retrogressive thaw flow. Area was burnt prior to failure. GSC photo 1996-133D by L.D. Dyke.

flow). They are generally triggered by unusually warm temperatures or some disturbance of the vegetation mat. Either instance will result in excessive deepening of the annual active layer which, if icy sediment is thawed, may detach and move downslope. The landslide tends to expand laterally as adjacent icy sediment also thaws. This type of failure is common in ice-rich terrain following a forest fire if the insulating organic mat is damaged or destroyed. If the removal of the water-saturated sediment continually exposes massive ice or icy sediments at greater depth, an active layer detachment may develop into a retrogressive thaw flow.

Retrogressive thaw flow slides have a characteristic bowl shape with a steep headwall and low angle tongue (**Figs. 2a-b**). The headwall gradually erodes upslope as massive ground ice or icy sediments thaws in the scarp and the resulting water saturated sediment flows downslope away from the scarp. Once the massive ice or icy sediment is exposed in the headwall, a seasonal cycle becomes established, beginning in summer when snow melts away from the scarp face. Water derived from snow melt and melting of ground ice helps to clean the scarp face of debris that may have accumulated the previous season. As sediment is released from the melting ice, it falls, slides or flows down the scarp face. Melting of the ice undercuts the active layer at the top of the scarp and the undercut peat and sediments detach and fall down to the base. These become incorporated into the water and debris at the base of the scarp face and flow downslope. Eventually the slide stabilizes as the face becomes buried by debris, the ice content of the sediment at the scarp decreases, or the slope of the scarp decreases. Retrogressive thaw flow slides may be initiated by any process or event which results in the exposure of massive ice or icy sediment.

Debris flows, a rapid flow of water-saturated sediment, occur in areas of higher relief. These flows are typically long narrow flows which widen into debris fans at their base. They may be triggered by extreme rainfall or unusually deep seasonal thaw in an abnormally warm summer. In mountainous areas, active layer detachments formed in burn scars may develop into debris flows if large amounts of meltwater is produced by the thawing of newly exposed ground ice.

Rotational slides involve the downslope movement of a rigid block of sediment along a curving failure plane, such that the toe of the block extends well beyond the original slope and the original upper surface of the block is generally back-tilted towards the scarp of the landslide (**Figs. 3a-b**). Such failures may occur as an individual block or as a stepped series of blocks. They are commonly induced by undercutting of the bank by river erosion. Pres-

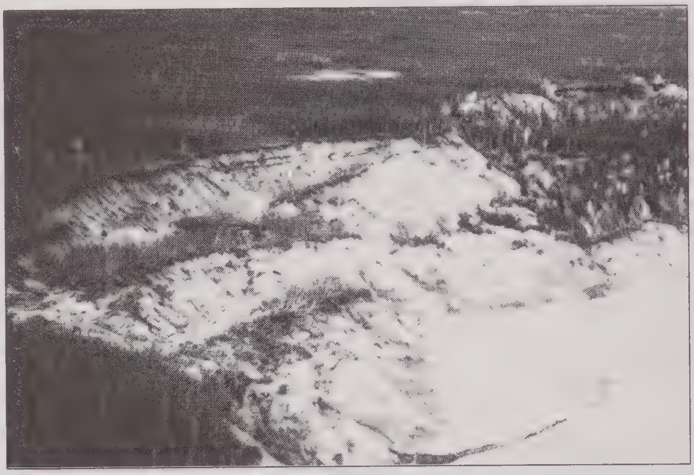

Figure 3a. Large rotational slide in glaciofluvial sands 90 km west of Norman Wells. GSC photo 1996-133A by P.A. Egginton.

Figure 3b. Closeup along one block in the landslide. Surface of the block (note the trees) is tilted back towards the headwall, indicating that the movement was rotational. GSC photo 1996-133C by L.D. Dyke.

sure of ground water, confined beneath the permafrost layer, is probably an important contributor in these failures.

Geological Controls

The type of slope failure that occurs at any given location will depend on the relief, geology, and local permafrost and groundwater conditions, as well as the particular trigger mechanism. Certain geological materials are particularly prone to slope failure. Fine grained sediments (silts and clays) are commonly ice-rich, with ice content varying from ice crystals to massive lenses of pure ice. These fine grained sediments are found in parts of the Mackenzie and adjacent valleys that were temporarily flooded by the huge glacial lakes that existed during retreat of the glaciers at the end of the ice age (**Fig 4**). Although closely associated with these lacustrine silts and clays, high ice contents may also occur in fine grained colluvium and fine matrix till. In ice-rich fine grained sediments, slope instability, due to the low strength of sediments when ground ice thaws, results in flow-type landslides. If relief is sufficient, these flows move very rapidly. Although much less common, sands, if well saturated, also may flow rapidly downslope as a debris flow.

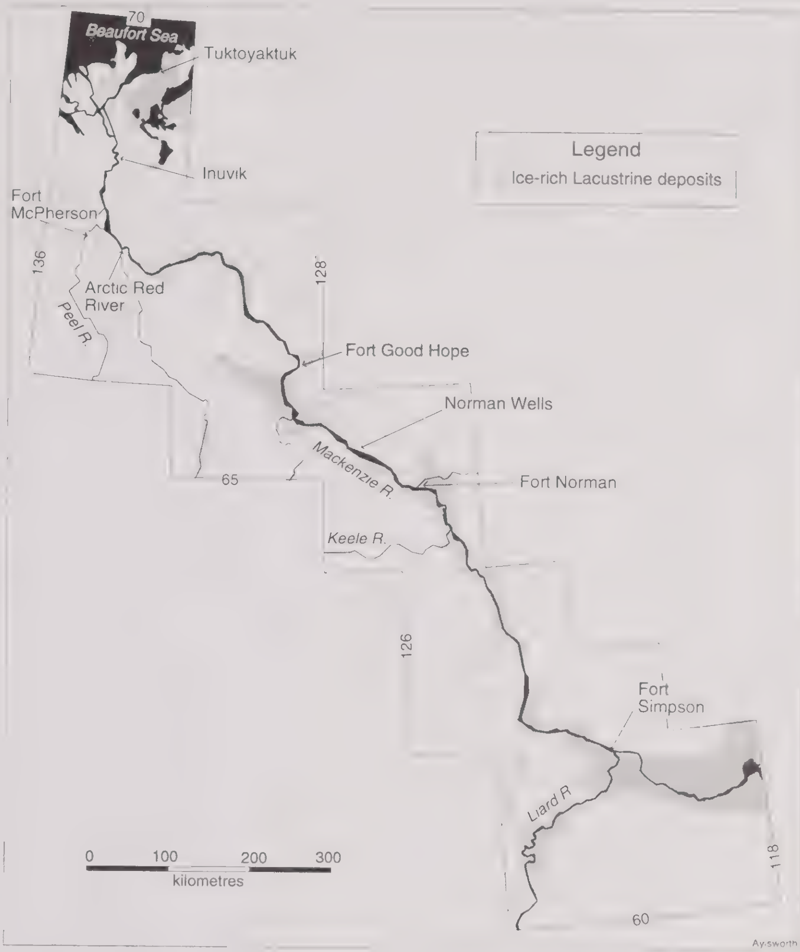

Figure 4. Distribution of lacustrine sediments, commonly silt and clay, in the Mackenzie and adjacent valleys. These fine grained sediments are generally ice-rich and very susceptible to slope failure. In places, varying thicknesses of deltaic or fluvial sand may overlay these fine grained sediments.

Coarse grained sediments (sands and gravels) are less likely to contain ice in excess of the pore volume. Although several environments of deposition are associated with coarse grain sediments, the most critical for landsliding is a deltaic environment where thick deposits of sand and gravel have been deposited overlying finer sediments along the margins of the above mentioned glacial lakes. Sands and gravels tend to fail in blocks as rotational slides. Commonly these occur along steep river banks where most of the bank is formed of highly permeable sands and gravels which overlie a finer layer of clay near the base. Failure occurs through frozen sands and continues into unfrozen clays. Moving southward, in the mid-Mackenzie Valley, the height of the river bank is often greater than the depth of permafrost, so that ground water is free to move toward the bank through the sand and gravel between the overlying permafrost and underlying clay layer. Elevated pressures in this water may be an important contributor to slope failure and removal of sediment by groundwater discharge may promote undermining of sediments masses (Burton et al., 1995).

Thermal and climatic influences

Although many landslides in the Mackenzie region

are related to earthquakes or river erosion, many are also related to climatic or thermal factors. Ground ice is associated with many, perhaps most, landslides. Thermal instability in permafrost slopes can result from changes in proximity of warm waters, exposure of ground ice by either frost cracking or shoreline erosion, or from the destruction of the insulating organic cover by fire or other causes. Other landslides are directly related to extreme climate events such as abnormally high precipitation events or high summer temperatures. Because so much of the Mackenzie valley contains permafrost and icy sediments are common, any warming, whether annual or longer term, can result in the deepening of the active layer, the melting of interstitial ice, and inducement of a landslide. Such occurred in 1989 when a record warm summer resulted in several major debris flows. Climate change implies not only warming temperatures, but some change in annual precipitation. Numerous examples of slope failure following heavy rainfall have been documented. Heavy rain may directly saturate the ground resulting in mobilization of the slope, or increase the pore water pressure to the point of instability, or rain-swollen rivers may erode the base of their banks, inducing landslides. In ice-rich permafrost areas, the other precipitation extreme — drought, can also trigger landslides.

In the Mackenzie area the frequency of forest fires is significantly increased during droughts. If ground conditions are very dry, the entire organic mat can be burnt, exposing icy sediments, leading to an active layer detachment failure, and possibly mobilizing the slope in a rapid debris flow. Even under present climatic conditions a definite link between fire and landslides can be made. Following the large forest fires of 1994 and 1995 in the vicinity of Fort Norman, numerous flows developed along the banks of the Mackenzie River and its tributaries. Thus if fire frequency increases in the future, the frequency of skin flows can be expected to increase.

Implications of global warming

Many landslides in the Mackenzie Valley are related to extreme climate events or thermal instabilities. If regional climate change is to occur in the Mackenzie Valley as suggested, then, at the least, there will be a period of dynamic adjustment to these new conditions.

An increase in winter snow cover, or an increase in winter air temperatures, or summer temperatures, or any combination will induce ground temperature warming. Given the prevalence of permafrost and icy sediments in this area, any regional ground temperature warming that might occur will increase the frequency of landslides in the area, at least in the short term. An increase in extreme precipitation events will result, for at least some period, in an increase in landslides. Increased fire will most definitely result in increased landslide activity.

At a regional scale, those areas most susceptible to landslides in the event of climatic warming are likely to be areas that presently are experiencing significant number of landslides. At a more localized scale, terrain sensitivity will be dependent on local geology, permafrost and ground ice conditions. Sites most susceptible to climatically induced landslides include ice-rich, fine-grained sediments (**Fig. 4**) on slopes close to bodies of water or rivers, or frozen coarse-grain sediments overlying clay or clayey till in steep sections along river banks where permafrost does not extend to the base of the section.

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5

VEGETATION

Vegetation Response to Global Warming: Interactions Between Boreal Forest, Wetlands and Regional Hydrology

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Introduction

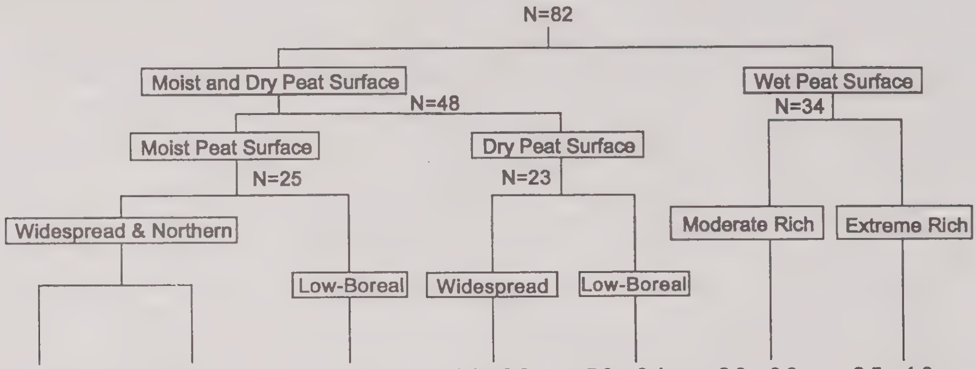
How climate change will affect peatlands is an important question in the Mackenzie River Basin as peatlands occupy 75-100% of the land in some areas of the basin (National Wetlands Working Group 1986). Increases in annual temperatures in northern locations are anticipated to be in the order of 3.7 to 4.6 °C by the middle of the 21st century (Cohen 1993). Elevated temperatures are expected to produce a drier climate that will affect site water balance and cause shifts in the distribution of ecosystems on a global scale (Houghton *et al.* 1990, Vitousek 1994) These effects will be quite noticeable in such ecosystems as peatlands which are sensitive to both climate and water level fluctuations. Peatland formation is a function of two climatic variables, precipitation and evaporation and generally peatlands occur where evaporation does not exceed precipitation (Gignac 1993). Macroclimate not only affects the presence of peatlands, but also the distribution of different bog forms, and the height they attain above the surrounding landscape (Moore and Bellamy 1974, Ivanov 1981, Belland and Vitt 1995). Peatland vegetation is very sensitive to climate as the distribution and abundance of bryophyte species follows environmental and climatic gradients (Gignac and Vitt 1990, Gignac *et al.* 1991, Gorham and Janssens 1992, Nicholson *et al.* 1996). Changes in the height of the water table cause changes in the presence, absence, and abundance of bryophyte species. Because of their sensitivity, changes in peatland vegetation should offer an early warning of large scale climate related changes before they occur in such slightly more climatically stable and larger ecosystems as the boreal forest.

The relationships between the various climatic and environmental gradients which underlie the abundance and distribution of peatland bryophytes can be modelled (Nicholson and Gignac 1995). Producing a model that will predict the impact of climate change on peatland bryophytes will allow an assessment of the relative impact on peatland distribution, local environmental gradients, and the relative position of the southern boundary of the boreal forest. The objectives of this project were to: 1) determine the relationships between peatland bryophytes and environmental and climatic gradients, 2) model the relationships using indicator species and response surfaces, 3) outline the current distribution of peatlands in the Mackenzie River Basin, 4) predict how peatland distribution is likely to change under two times current CO_2 levels, and 5) determine the impact of the predicted distribution on local water levels. The methodology for this project is reported in the MBIS interim report #2 (Nicholson *et al.* 1994), and in Nicholson *et al.* (1995).

Materials and methods

Preliminary Results and Revisions

Our preliminary results (MBIS interim report #2) reported that eight TWINSPAN bryophyte groups existed in the basin. This was subsequently revised into seven groups. The new TWINSPAN dendrogram identifying the peatland types, the climatic and environmental parameters for each group and the indicator species diagnostic of each division are presented in **Figure 1** (Nicholson *et al.* 1996). The revised detrended canonical correspondence analysis (DCCA) with seven peatland types indicates that the most important gradients affecting peatland distribution in the Mackenzie River Basin are pH ($r = -0.86$), water chemistry (Ca^{2+} $r = -0.49$, Mg^{2+} $r = -0.48$), and height above the watertable ($r = 0.42$). Although slightly secondary, climate, particularly precipitation variables, annual temperature, and length of the growing season are related to the geographical distribution of the stands in the study area. Climatic variables that were significantly correlated ($p<0.001$) with peatland distribution were thermal season precipitation (tspp, $r = -0.40$), annual precipitation (ypp, $r = -0.36$), growing season (gs, $r = -0.29$), and mean annual temperature (temp, $r = -0.27$). Eigenvalues were 0.68 for axis 1, 0.40 for axis 2, 0.30 for axis 3, and 0.19 for axis 4. Differences in results presented in interim report #2 and this report, consist of small changes in the correlation coefficients and



pH	4.9 ± 0.9	4.1 ± 0.8	4.2 ± 0.5	4.4 ± 0.6	5.3 ± 0.4	6.3 ± 0.9	6.5 ± 1.0
Ca (mg/l)	8.7 ± 12.3	5.3 ± 2 .4	1.7 ± 0.8	5.1 ± 2.8	18.5 ± 17.7	19.6 ± 17.2	57.0 ± 47.5
Mg (mg/l)	2.5 ± 3.2	2.2 ± 1.8	0.4 ± 0.3	1.7 ± 1.3	4.0 ± 2.7	4.6 ± 3.6	11.7 ± 7.7
Na (mg/l)	4.1 ± 5.8	2.8 ± 2.0	5.1 ± 2.6	3.9 ± 2.6	8.6 ± 5.5	7.3 ± 11.5	7.5 ± 2.3
Gs (days)	169 ± 18	170 ± 12	191 ± 3	174 ± 23	187 ± 6	186 ± 9	179 ± 21
Temp (oC)	-2.3 ± 2.8	-2.5 ± 1.5	1.1 ± 0.6	-1.6 ± 3.6	0.5 ± 0.6	0.1 ± 1.4	-0.7 ± 3.1
Tspp (mm)	248 ± 82	235 ± 54	343 ± 18	267 ± 86	346 ± 56	337 ± 54	301 ± 83
Ypp (mm)	398 ± 91	398 ± 49	486 ± 12	417 ± 87	498 ± 72	482 ± 65	453 ± 87
Height (dm)	1.8 ± 1.0	2.1 ± 0.8	2.4 ± 1.0	3.4 ± 1.3	2.5 ± 0.8	1.4 ± 0.7	1.0 ± 0.9
Σ Sphagnum	10.4	14.0	11.5	11.4	4.1	1.7	0.7
Σ Amblystegiaceae	2.4	2.0	1.1	1.3	1.1	6.0	7.4
Sample size (N)	15	3	7	14	9	27	7
Community group	1	2	3	4	5	6	7
Peatland Type	**Widespread Poor Fens**	**Peat Plateaus with Thermokarst pools**	**Low-Boreal Bogs**	**Bogs & Peat Plateaus without Thermokarst pools**	**Low-Boreal Dry Poor Fens**	**Moderate Rich Fens**	**Extreme Rich Fens**

Figure 1. TWINSPAN dendrogram outlining the division of 82 peatlands in the Mackenzie River basin into seven TWINSPAN bryophyte stand groups and seven peatland types. Values are teh means and standard deviations of climatic and environmental gradients significant on the first DCCA asix of each TWINSPAN stand group.

a switch in the order of importance between height above the water table, and the elements Ca^{2+} and Mg^{2+}.

Building the Model in climate space

Three-dimensional response surfaces were generated for 21 indicator species along the most important climatic variables. Response surfaces were produced by gridding observed abundance data using distance-weighted means (Gignac *et al.* 1991). The Model consists of assembling the 21 individual indicator species into a predictive indicator community at each grid node on the response surface (Gignac 1993). The predictive indicator community contains abundance values for each indicator species at each grid node.

To test the accuracy of the Model to determine the geographical location of each type of peatland, the extant distribution of the seven peatland types sampled were plotted on a map. The climatic values for mean annual temperature and precipitation, and length of the growing season that defined each sampled peatland were then used to select an indicator community at the nearest grid node in climatic space. This indicator community was then compared to the actual communities that defined the seven peatland types. This was accomplished by comparing the abundances of bryophyte species for the indicator community with the abundances of the same species that indicate an actual type of peatland in **Table 1** using a dissimilarity coefficient. Thus, each indicator to be tested produced seven dissimilarity values, one for each type of peatland. The least dissimilar value identified the analogue type of peatland which was originally defined only by three climatic values. Since the analogue type of peatland was reconstructed for an actual peatland, the geographical location of the latter was used to plot the location of the

analogue. The relationship between the analogue and actual geographic locations was analyzed statistically using an ANOVA to test the confidence limits and significances that the locations had the same latitudes and longitudes.

The future climatic values were obtained from two General Circulation Models for 2X present CO_2 levels: the Canadian Climate Centre Model (CCC) and the Geophysics Fluid Dynamics Laboratory Model (GFDL). To determine the geographic distribution of each peatland type at $2XCO_2$ levels at equilibrium, the climatic data generated by the GCMs for several locations (identified by latitude and longitude) in the study area were gridded in climatic space. Since each grid node was associated with an indicator community, each geographical location is identified by a new indicator community for $2XCO_2$ levels. The peatland type indicated by each community was determined using dissimilarity coefficients computed by comparison with the communities listed in **Table 1**. The least dissimilar community indicated the peatland type. Thus, a peatland type was associated with each geographical location identified by climatic data generated by the GCMs and subsequently mapped. However, some caution must be used to interpret this data. Owing to the relative paucity of peatland data for northern areas of the Basin, locations that do not have actual data associated with it were used to plot the various peatland types. Peatlands may not actually exist in those specific locations because of the topography. Therefore, the predictions indicate an area in which each type of peatland could be found, given that the topography will permit peatland development, i.e. where slopes are on the order of 1 to 1000 (Gorham 1991). Confidence limits for the accuracy of these predictions were previously determined by comparing the locations of analogue and actual peatland locations.

Because the southern limit of peatlands occurs in an area south of the Mackenzie River Basin, the distribution of extant peatlands in the Basin could not be used to define the southern limit. To determine the southern limit of peatlands, a reverse process was used, where the southern limit was defined by the northern limit of the absence of peatlands in the area south of the Basin. A peatland distribution map for Alberta (Nicholson and Halsey 1992) was used to select localities having permanent weather stations and that did not have any peatlands directly south of them. Localities having permanent weather stations that satisfied this criteria were then plotted in geographic space.

Mean annual temperature and

Table 1. Mean abundances of bryophyte indicator species for seven peatland types as determined by a TWINSPAN analysis of 82 stands in the Mackenzie River Basin. Peatland groups are: 1 = widespread poor fens; 2 = peat plateaus with thermokarst pools; 3 = low-boreal bogs; 4 = bogs and peat plateaus without thermokarst pools; 5 = low-boreal dry poor fens; 6 = moderate rich fens; 7 = extreme rich fens. n = number of stands for each type.

	TWINSPAN group						
Species	1	2	3	4	5	6	7
Mylia anomala (Hook.) S. Gray	4.2	3.2	0.9	4.2			
Drepanocladus fluitans (Hedw.) Warnst.	0.4	1.0		0.1			
Sphagnum riparium Aongstr.	18.0	18.0		0.1			
Pleurozium schreberi (Brid.) Mitt.	0.5	3.2	3.2	20.2	27.8	0.7	
Polytrichum strictum Brid.	6.4	3.2	4.2	4.2	2.4	0.4	
Sphagnum magellanicum Brid.	2.3	3.2	36.0	0.6		0.1	
Sphagnum angustifolium (C. Jens.) C. Jens.	15.0	16.7	31.8	0.6	0.9	0.3	
Dicranum undulatum Brid.	0.5	1.0	0.7	6.4	11.9	0.4	
Aulacomnium palustre (Hedw.) Schwaeger.	3.2	0.7	10.4	3.2	15.0	9.7	0.9
Drepanocladus vernicosus (Mitt.) Warnst.	0.1		0.4			9.7	0.3
Hylocomium splendens (Hedw.) B.S.G.	0.4	1.0		4.7	7.3	0.9	0.3
Hypnum pratense W. Koch					0.4	1.2	0.4
Meesia triquetra (Richt.) Aongstr.	0.3					0.7	0.3
Sphagnum fuscum (Schimp.) Klinggr.	19.3	66.1	22.0	34.9	2.3		1.0
Tomenthypnum nitens (Hedw.) Loeske	1.0		1.5	0.9	7.6	7.3	16.7
Campylium stellatum (Hedw.) C. Jens.					0.4	0.6	25.8
Brachythecium mildeanum (Schimp.) Schimp.	0.1					1.2	
Drepanocladus polycarpus Blandow						0.6	
Drepanocladus sendtneri (Schimp.) Warnst.						0.7	
Scorpidium scorpioides (Hedw.) Limpr.							1.5
n	15	3	7	14	9	27	7

precipitation, and length of the growing season were analyzed for each locality in order to determine the northern boundary of the absence of peatlands in climatic space. This boundary was defined by the following parameters: 1) mean annual temperature ≥ 3 °C or 2) mean annual temperatures > 0 °C, mean annual precipitation < 450 mm, and length of the growing season ≥ 190 days. For the latter parameter, all three criteria must be met before it was concluded that there was an absence of peatlands. To test this hypothesis, climate data was gridded for all localities having permanent weather stations including those in the Basin using the same grid as previously described. Localities having gridded climatic dimensions that fell within the hypothesized parameters were selected and plotted in geographic space. An ANOVA was used to statistically determine the confidence limits of this reconstruction by comparing the actual to the reconstructed latitudes and longitudes. To determine the southern limits of peatlands at 2X present CO_2 levels at equilibrium, localities in both GCM scenarios that satisfied the hypothesized criteria were determined not to have peatlands to the south of them. All computations, maps, and statistical analyses were done on a microcomputer using the Statistical Analysis System (SAS) package.

Building the Model in ecological space

Two-dimensional response surfaces were generated in ecological space along pH and height relative to the water table gradients for the same 21 indicator species that were used to build the Model in climate space. The response surfaces for the 21 species were assembled into a predictive indicator community in ecological space where each grid node had abundances for each indicator species (Gignac 1993). To determine the distance between the water table and the peat surface for 1X present CO_2 levels, each indicator community that was predicted by the Model in climate space for each geographical location, was compared to the indicator communities found at all the grid nodes in ecological space using a squared-chord distance dissimilarity coefficient. The least dissimilar community among those in ecological space was selected and, from the grid node at which it occurred, the height above the water table was determined. Since there can be several types of peatlands at each locality, each one having a different distance between the water table and the peat surface, depths were calculated as means ± standard deviation. The same method was used to determine the height relative to the water table at equilibrium for the same localities for 2X present CO_2 levels. Changes in the depth to the water table as a result of climate change were calculated by subtracting the depth of the water table for a peatland at $1XCO_2$ from the depth for the peatland that replaced it at $2XCO_2$. Changes were then meaned for each locality.

Results

Extant Peatlands and their Distribution

1) Widespread Poor Fens, moist, weakly minerotrophic fens dominated by *Sphagnum angustifolium, S. fuscum, Polytrichum strictum,* and *S. riparium.* The extant distribution of this group in geographic space is widespread but disjunct and is located from the low-Boreal to the Subarctic ecoclimatic regions (**Figure 2**). Disjunctions occur in the north central part of Alberta and in the Northwest Territories. These disjunctions are an artifact of the original sampling since very few sites were studied in both areas. It is very likely that poor fens are located in across the study area.

2) Peat Plateaus with Thermokarst Pools, weakly minerotrophic mid to high-Boreal peatlands with moist peat surfaces containing more of hummock forming Sphagna *(S. fuscum, S. magellanicum)* and bryophytes commonly found beneath dry forest canopies *(Pleurozium schreberi, Hylocomium splendens).* This group has a relatively narrow distribution and ranges from the mid to high-Boreal ecoclimatic regions near the Alberta/NWT border. The location of this group is mostly determined by the climate since thermokarst pools are not found further south because of the absence of permafrost nor further north because pools are rare as permafrost generally underlays the entire peatland.

3) Low-Boreal Bogs, acidic, oligotrophic peatlands characterized by an abundance of hummock forming Sphagna, *(Sphagnum magellanicum, S. fuscum),* feather moss *(Pleurozium schreberi),* and the lawn species *Sphagnum angustifolium.* This group is restricted to southerly areas in the Mackenzie River Basin and is found in the low-Boreal ecoclimatic region.

4) Bogs and Peat Plateaus without Thermokarst Pools, dry, acidic peatlands that range across the Boreal-Subarctic ecoclimatic regions and are dominated by *Sphagnum fuscum, Pleurozium schreberi, Dicranum undulatum, Hylocomnium splendens,* and *Polytrichum strictum.* This group is widespread and ubiquitous across the Mackenzie Basin with the exception of a disjunction in the north central portion of Alberta. Even though species composition is approximately the same for all peatlands in this group, there are two phases that are affected by the climate. In the northern portion of the Basin, the dryness of the peatlands is caused by perma-

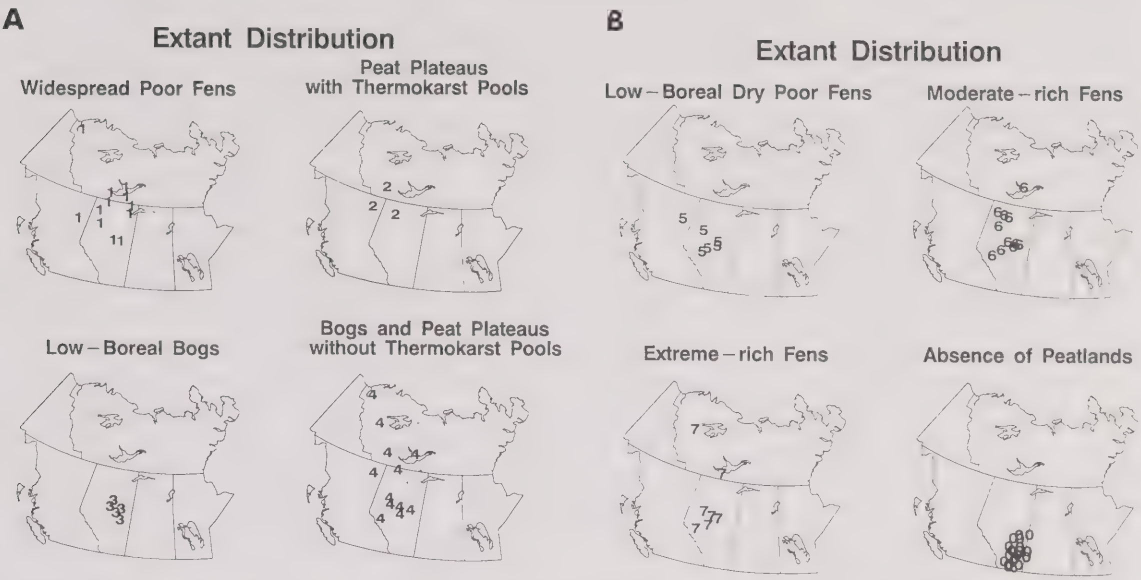


Figure 2 (A & B). Geographical locations of extant peatlands analyzed in the Mackenzie River Basin divided according to peatland type.

frost which raises the peat surface well above the water table (Halsey *et al.* 1993). Only a few small thermokarst pools are present in these peatlands, hence the majority of the peatland surface is dry and forested. Permafrost is absent in the southern low- and mid-Boreal phase and in those areas, the dryness is caused by high evapotranspiration rates promoting tree cover and feathermoss dominance.

5) Low-Boreal Dry Poor Fens, dry, minerotrophic fens ranging from the low to mid-Boreal ecoclimatic regions under warm, reasonably moist climatic conditions. Peatlands in this group are relatively dry and *Sphagnum* dominated but are also characterized by populations of *Pleurozium schreberi, Hylocomium splendens, Aulacomnium palustre,* and *Tomenthypnum nitens. Pleurozium and Hylocomium* indicate forest cover while *Aulacomnium* and *Tomenthypnum* are minerotrophic species commonly found in rich fens (Gignac and Vitt 1990).

6) Moderate-rich fens, wet minerotrophic fens characterized by *Drepanocladus vernicosus, Aulacomnium palustre, Tomenthypnum nitens,* and *Bryum pseudotriquetrum.* This type of peatland is the most abundant type in the Mackenzie River Basin. They occur under variable climatic conditions ranging from low- to high-Boreal ecoclimatic regions. The absence of these peatlands in the most northerly areas of the Basin may be a result of the paucity of sampling locations. Moderate-rich fens are probably located throughout the area but are most abundant in the southern portion of the Basin where several sites were analyzed at each weather station, but were represented geographically by only one locality, that of the nearest weather station.

7) Extreme-rich fens, wet minerotrophic fens that are dominated by *Campylium stellatum, Scorpidium scorpioides, Drepanocladus revolvens, Bryum pseudotriquetrum,* and *Tomenythpnum nitens.* They are wide ranging in distribution from the low-Boreal to the low-Subarctic ecoclimatic regions. Although they are widespread, their distribution indicates that they are more prevalent in the low-Boreal than in other regions. Again the lack of large scale sampling in northern regions may be limiting the number of locations in which they were found.

The southern limit of peatland distribution is indirectly indicated by the absence of peatlands (group 0). In Alberta, the southern limit of peatland distribution roughly parallels the southern boundaries of the Mackenzie River Basin. In most areas, it is approximately 100 km south of the boundary. The southern limit dips to the south along the Rocky mountain foothills in the southwestern portion of Alberta. However, because of higher elevations, the climate in these areas approximates that found in more northerly areas.

Analogue distribution

The analogue distribution of widespread poor fens (group 1) closely resembled their extant distribution in geographic space. A statistical analysis comparing latitudes for reconstructed and actual localities, revealed that although the range is the same, the mean and standard deviation were slightly higher for the analogue version (**Table 2**). There was a 70% probability that variances about the means of the latitudes and a 62% probability that the variance about means of the longitudes were the same. An analysis of the longitudes showed the reconstructed data having a slightly more northerly and westerly distribution than the actual data.

The analogue distribution of peat plateaus with thermokarst pools (group 2) was restricted to the mid- to high-Boreal ecoclimatic regions. This ecoclimatic distribution was the same as that of the actual data, but the reconstructed data had shifted slightly east. The means of the latitudes were slightly different, with the reconstructed latitudes having a slightly more northerly distribution, but the ranges were the same for both data sets. Confidence limits for the equality of variances about the means were 70% for latitude and only 22% for longitude.

The ecoclimatic distribution of the analogue version of low-Boreal bogs (group 3) was also restricted to the low-Boreal ecoclimatic region. The reconstructed latitudinal distribution was slightly more widespread than the distribution of the actual data as indicated by the minimum and maximum values for both data sets. Means for latitudes were almost identical and the significance indicates that there was a 73% probability that variances about the means for both sets were the same. The reconstructed distribution for longitudes however was much less accurate producing confidence limits for variances about the means of only 10%. The analogue distribution was definitely more westerly than the actual distribution as indicated by higher mean, minimum, and maximum values.

The reconstructed version of bogs and peat plateaus without thermokarst pools (group 4) had fewer sites than the original data set. The analogue version missed a few sites in the middle of the range of extant peatlands, but the distribution of populations was very similar along the

Table 2. Comparison between the distribution of 7 groups of extant peatlands in the Mackenzie River Basin and the reconstructed distribution based on the model. n = number of sites. sd = standard deviation; min = minimum; max = maximum; prob = probability that variances are equal. Peatland groups are: 1 = widespread poor fens; 2 = peat plateaus with thermokarst pools; 3 = low-boreal bogs; 4 = bogs and peat plateaus without thermokarst pools; 5 = low-boreal dry poor fens; 6 = moderate rich fens; 7 = extreme rich fens.

		latitude				longitude			
version	n	mean ± sd	min	max	prob	mean ± sd	min	max	prob
Group 1									
extant	15	58.97 ± 3.56	55.17	68.30		116.73 ± 5.56	111.95	133.48	
analogue	15	59.49 ± 3.79	55.17	68.30	0.70	117.79 ± 5.90	111.95	133.48	0.62
Group 2									
extant	3	59.74 ± 1.85	58.52	61.87		120.34 ± 2.88	117.10	122.58	
analogue	4	60.26 ± 1.39	58.52	61.87	0.70	116.60 ± 3.86	117.90	121.30	0.22
Group 3									
extant	7	55.08 ± 0.32	54.62	55.35		113.72 ± 1.05	112.50	114.82	
analogue	6	54.97 ± 0.77	53.58	55.73	0.73	115.06 ± 1.63	113.18	117.20	0.10
Group 4									
extant	14	58.39 ± 4.56	53.37	68.30		118.23 ± 6.05	112.50	133.48	
analogue	9	58.86 ± 5.63	53.28	68.30	0.82	119.14 ± 6.97	113.68	133.48	0.74
Group 5									
extant	9	54.96 ± 1.26	53.58	57.00		116.60 ± 2.51	113.90	122.37	
analogue	4	54.92 ± 1.26	53.58	56.23	0.96	116.69 ± 0.80	115.67	117.43	0.95
Group 6									
extant	27	55.69 ± 1.85	53.23	62.47		114.53 ± 1.52	112.50	118.68	
analogue	18	56.59 ± 2.22	53.23	61.33	0.15	115.67 ± 3.24	111.95	122.58	0.12
Group 7									
extant	7	57.12 ± 4.33	53.37	65.28		117.52 ± 4.27	114.03	126.80	
analogue	7	57.62 ± 3.64	53.37	61.87	0.82	116.27 ± 2.95	111.97	121.35	0.54

latitudinal gradient as indicated by the means, minima, and maxima. The level of significance that the variances about the mean latitudes were equal is 82%. The southern limit of the distribution of actual sites was slightly more northerly than the southern limit for the reconstructed data. Values for the longitudes were also very similar in both data sets, with the reconstructed data having a slightly more westerly distribution than the actual sites.

Although the analogue version reconstructed fewer sites than there were in the original data, confidence limits for the equality of the distribution of low-boreal dry poor fens (group 5) along both latitudinal and longitudinal gradients were very high at 96% and 95%. However, minimum and maximum values for both data sets indicated that the actual sites were more widely distributed particularly along the longitudinal gradient than the reconstructed data. Minimum values for the latitudes indicated that the southern limit for group 5 was the same for both versions. The Model was unable to predict the geographical location of the northern outlier for this group.

Although there were fewer analogue moderate-rich fens (group 6) than in the original data set, their number was still greater than the number reconstructed for all other peatland types. The geographical distributions of extant and analogue peatlands appeared similar because they had approximately the same ranges and the greatest number of sites occurred near the southern limits of the Basin. The statistical analysis however revealed that there were major differences between data sets caused by a greater and more widely distributed number of sites in northern areas in the reconstructed version as indicated by the means of the latitudes and the ranges of the longitudes. These differences resulted in a significance level for the equality of variances about the means of only 15% and 12% along the latitudinal and longitudinal gradients respectively. The southern limits of the distributions for both extant and reconstructed latitudes were the same, but the northern limit was higher for the extant data.

The geographic range of extreme-rich fens (group 7) was also very similar between extant and analogue versions as indicated by the means of the latitudes and longitudes. Differences between data sets are: 1) there were more actual sites in the southern portion of the Basin than were reconstructed by the Model and vice versa; and 2) the northernmost existing site was not reconstructed by the Model. These differences produced significance levels for the equality of variances about the mean of 82% and 54% for latitude and longitude respectively. However, the southern limits for the distribution of both data sets as indicated by the minimum latitudes were identical. As was the case for group 5, the Model was unable to predict the location of the northernmost outlier for this group.

An analysis of the geographic distribution of weather stations that did not have peatlands located to the south of them (group 0) revealed that both data sets were identical. Thus, the hypothesis stating that if: 1) mean annual temperatures ≥ 3 °C or 2) mean annual temperatures > 0 °C, mean annual precipitation < 450 mm, and length of the growing season ≥ 190 days, there are no peatlands present was correct. The northern limit of the absence of peatlands or, conversely the southern limit of peatlands was thus accurately defined.

Projected distribution (2XCO_2)

Projected distributions of peatland types at equilibrium based on data obtained from both climate change scenarios indicated that the southern limit of peatlands in the Mackenzie River Basin straddled 60° latitude (**Figure 3** & **4**). As indicated by the absence of peatlands, the southern limit for peatlands based on the CCC scenario was located along 60° latitude, while it was slightly lower based on the GFDL model. This translated to a northward migration of approximately 780 km. The Model predicted that moderate-rich fens (group 6) were the most abundant peatland type based on data obtained from both climate change scenarios. The second most abundant type for both scenarios were bogs and peat plateaus without thermokarst pools (group 4). However, apart from these similarities, the geographical distribution of each peatland type changed between scenarios.[3]

The projected distribution of widespread poor fens (group 1) was similar for both scenarios and covered most of the Basin north of 60° latitude, with a gap in the central portion of the study area. The Model also projected a higher density of sites approximately midway between 60° latitude and the Arctic Ocean, with slightly fewer sites for the GFDL version than the CCC version. The distribution of the groups with the GFDL data was slightly more northerly and easterly than the CCC version.

The projected distribution of peat plateaus with thermokarst pools (group 2) was quite different for each scenario. The GFDL version had relatively more sites than the CCC version and they were more widely distributed in geographical space. Predicted sites for the CCC version were located within a narrow area adjacent to the northern boundary of the Basin, while those for the GFDL version were found in the same area as well as the northern boundary and the eastern edge of the Basin.

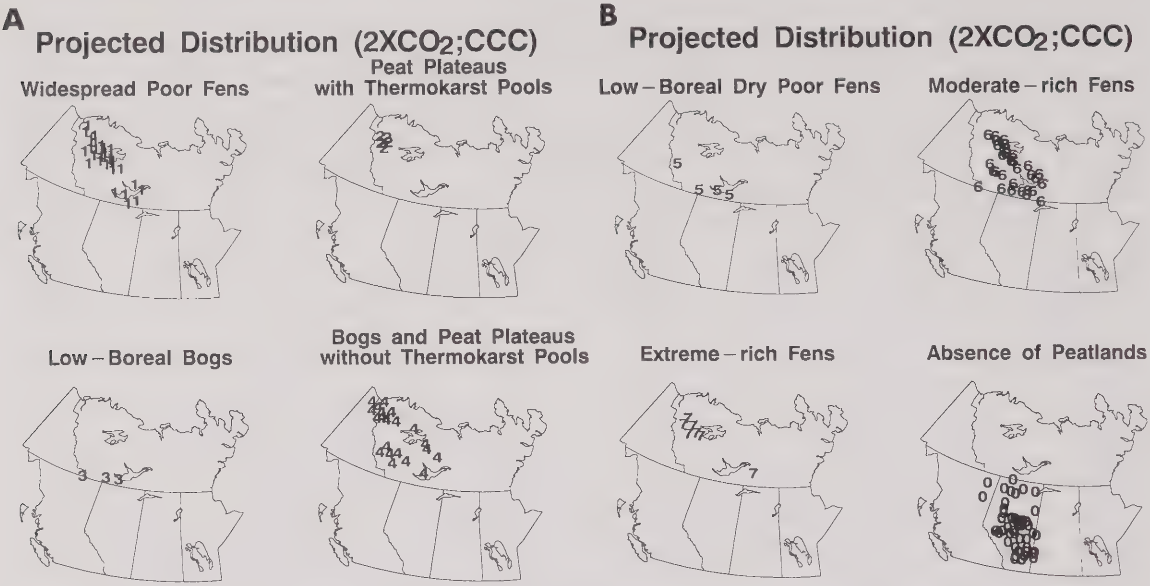


Figure 3 (A & B). Projected distribution by peatland type of sites in the Mackenzie River Basin as a result of global warming. Climatic data that were used by the model to generate the projected distribution of peatlands were obtained from the Canadian Climate Centres (CCC) Model for 2x present CO_2 concentrations.

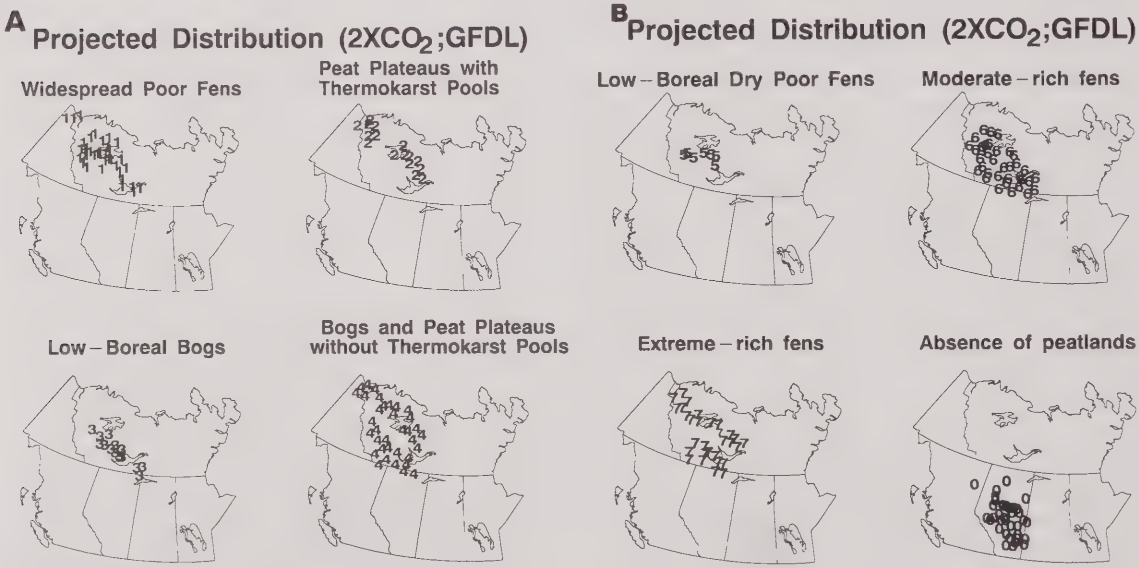


Figure 4 (A & B). Projected distribution of sites by peatland type in the Mackenzie River Basin as a result of global warming. Climatic data that were used by the model to generate the projected distribution of peatlands were obtained from the Geophysics Fluid Dynamics Laboratory (GFDL) Model for 2X present CO_2 concentrations.

The distribution of the three low-boreal bogs (group 3) was restricted to the southern limit of peatlands based on climatic data obtained from the CCC scenario. The Model predicted more sites using the GFDL scenario and these were distributed diagonally across the lower part of the Basin north of 60° latitude, and only those found in the southeast portion of their distribution formed the southern limit of peatlands.

Bogs and peat plateaus without thermokarst pools (group 4) were distributed throughout the Basin north of 60° latitude with only a narrow diagonal gap across the central portion of their distribution for both scenarios. The distribution of these peatlands formed the predicted southern limit of peatlands for the GFDL scenario but not for the CCC version. The projected distribution of these sites reached the northern boundary of the Basin for both versions. The CCC version had a slightly more northerly and westerly distribution than the GFDL scenario.

The distribution of low-boreal dry poor fens (group 5) was similar to that of the low-boreal bogs for the CCC scenario and, with the exception of one site, were mostly located along the predicted southern limit of peatlands. This peatland type was much more abundant and more widely distributed in the GFDL version. Sites were located throughout the Basin north of 60° latitude, including a relatively small area adjacent to the Arctic Ocean. The GFDL version had a more northerly and easterly distribution than the CCC scenario, and there were no sites on the predicted southern limit.

The projected distribution of moderate-rich fens (group 6) was similar for both scenarios. Sites were located throughout the Basin north of the southern limit of peatlands with the exception of a small area adjacent to the Arctic Ocean. Sites for both versions were found along the predicted southern limit of peatlands. There were relatively more sites projected by the CCC scenario than the GFDL version. The GFDL version had a slightly more southerly and easterly distribution than the CCC.

The number of extreme-rich fens (group 7) projected by the GFDL version was almost double the number predicted by the CCC Model. For the GFDL version, they were located throughout the Basin north of the predicted southern limit of peatlands but were much more abundant along the eastern boundary. They were generally found along a diagonal running northwest and they formed the predicted southern limit of peatlands only in the south central portion of their distribution. The distribution of this group based on the CCC scenario also formed a diagonal, but the distribution was mostly centred on a relatively small area in the northern part of the Basin. The distribution of the sites reached the Arctic Ocean for the GFDL version, but not for the CCC scenario.

Changes in peatland water table depths

Appendix 1 lists mean water table depths relative to the peat surface for peatlands located at 796 geographical locations identified by longitude and latitude in the Mackenzie River Basin. Depths were calculated by the Model based on predictive indicator communities generated from climatic data obtained from the CCC GCM for $1XCO_2$ and $2XCO_2$. Wherever the Model predicted an absence of peatlands at $2XCO_2$ (**Figure 3b**), a value of 8 dm was assigned as the water table depth. At this depth, the vegetation no longer responds to the water table (Laine *et al.* 1995) and the Model, which is based on vegetation responses, can no longer track changes in water table depth. Thus, the changes listed in Appendix 1 are minima, and actual changes for many localities, particularly in the southern areas of the Basin, could be substantially greater. However, wherever peatlands were predicted to persist at $2XCO_2$ (**Figure 3**), i.e. from 60° latitude to the Arctic Ocean, calculated changes are relatively accurate.

Changes in water table depths listed in Appendix 1 were summarized in **Figure 5**. Isolines were drawn by splining mean changes at each grid node and therefore do not indicate deviations or extremes in the data set (Appendix 1). As mentioned previously, wherever peatlands have disappeared in the $2XCO_2$ scenario, i.e. south of 60° latitude, changes in water table depths are underestimated. Changes in water levels gradually decrease from a maximum of -7 dm in the area of Lake Athabasca (59° latitude) to no change in the area just south of Great Bear Lake (63° latitude). In the area to the west of Great Bear Lake between 63° and 65° latitude, the water table was predicted to vary from 3 dm and, at some localities, up to 6.5 dm (Appendix 1) closer to the peat surface. North of 65° latitude, distances between the water table and peat surface would gradually decrease to a minimum of -1 dm.

Discussion

Strengths and limitations of the Model

With the exception of moderate-rich fens (group 6), the analogue distribution of sites in geographical space generated by the Model were accurate to within confidence limits for the equality of variances ≥ 70% along the latitudinal gradient (**Table 2**). Differences between the distribution of analogue sites and actual locations were mainly due to three factors: 1) the gridding process rounded cli

Figure 5. Projected minimum mean changes in the depth of the water table relative to the peat surface (dm) for peatlands in the Mackenzie Basin River Basin based on climatic data obtained from the Canadian Climate Centre (CCC) Model for 1X and 2X present CO_2 concentrations.

matic values thus losing accuracy; 2) indicator communities that were used to identify each group were quantified by mean species' abundances and did not account for deviations and these may have resulted in misidentifications of peatland types; and 3) the Model was unable to predict geographical outliers in groups 5, 6, and 7. The lack of accuracy for projecting latitudes for group 6 was more problematical. The most important reason, apart from those already listed for other groups, was that several sites in the southern section of the group's distribution had adjacent geographical locations and were therefore identified by only one value for each climatic variable. The Model could only predict one site for each location, thus could not recreate the proper variance about the mean.

The Model's accuracy for predicting longitude lacked resolution, particularly for groups 2, 3, and 6. The reasons already listed for the lack of accuracy for projecting latitudes also applied to longitudes. However, those problems were compounded by the absence of a strong climatic gradient along the longitudinal gradient and because of this, climate did not accurately define longitudes for many sites. For example, two sites having the same latitude but separated longitudinally had almost identical mean annual temperature and precipitation, and length of the growing season. The predictive Model had difficulty distinguishing between these sites since it was based on climatic variables rather than geographical locations, and because of this, it produced large errors for the variations about the means.

The Model was particularly efficient at predicting the southern limit of the distribution of each peatland type. A comparison between actual and analogue distributions revealed that minimum values for latitudes were identical for all groups, with the exception of groups 3 and 4, where there were only slight variations (**Table 3**). The Model was less accurate at predicting the northern limits of distribution. The largest variations occurred for groups 5, 6, and 7, with the northern limits for group 7 being the most seriously underestimated. This was an artifact of the lack of sampling sites in northern regions of the Basin which led to the Model's difficulty in correctly locating northern outliers.

To summarize, the following precautions must be taken when interpreting the projected geographical locations of peatland types as a result of global warming: 1) the longitude projected for each site may vary considerably; 2) the northern limit of the distribution of groups 5, 6, and 7 may be underestimated; and 3) the distribution of sites for group 6 may be too far north. However, the latitudinal distribution of sites for all groups, with the exception of group 6, and the southern limit of all groups can be predicted with a minimum of 70% confidence.

Projected distributions

The southern limit for each peatland type as well as the northern limit for the absence of peatlands appeared to be accurate for both the GFDL and CCC scenarios. The southern limit for the presence of peatlands meshes with the northern limit for the absence of peatlands. Since both projections were derived independently, they corroborated each other. Discrepancies between the southern limit of peatlands for the two scenarios was directly related to the climatic data. A comparison between climatic data for the GFDL and CCC Models revealed that for most localities, the GFDL version was colder and wetter. Mean values for mean annual temperature and precipitation for 101 localities in the Basin were -0.2 ± 5.1 °C and 379 ± 142 mm for the CCC scenario and -1.3 ± 4.7 °C and 446 ± 173 mm for the GFDL version. The colder wetter GFDL scenario produced a southern limit of peatlands below 60° latitude while the same limit based on data from the CCC scenario straddled the same longitude.

For both climate change scenarios, the distribution

Table 3. Projected geographical distribution of 7 groups of peatlands as a result of global warming in the Mackenzie River Basin. Predictions were based on climatic values obtained from two General Circulation Models for $2XCO_2$ levels at equilibrium: CCC = Canadian Climate Centre Model; GFDL = Geophysics Fluid Dynamics Laboratory Model. % = percentage of total number of sites in each group. sd = standard deviation; min = minimum; max = maximum. Peatland groups are: 1 = widespread poor fens; 2 = peat plateaus with thermokarst pools; 3 = low-boreal bogs; 4 = bogs and peat plateaus without thermokarst pools; 5 = low-boreal dry poor fens; 6 = moderate rich fens; 7 = extreme rich fens.

		latitude			longitude		
version	%	mean ± sd	min	max	mean ± sd	min	max
Group 1							
CCC	15.6	64.76 ± 1.82	60.35	68.38	123.11 ± 6.01	110.27	132.90
GFDL	15.0	65.29 ± 1.83	61.60	69.05	122.37 ± 6.35	110.86	139.63
Group 2							
CCC	2.2	66.25 ± 0.47	65.55	66.92	130.05 ± 0.53	129.32	130.70
GFDL	5.0	66.16 ± 1.36	63.17	68.58	124.78 ± 9.01	110.38	140.38
Group 3							
CCC	0.9	60.82 ± 0.09	60.75	60.88	118.49 ± 2.11	117.00	119.98
GFDL	2.7	62.52 ± 1.34	59.90	64.55	117.71 ± 4.66	110.13	126.25
Group 4							
CCC	31.3	66.02 ± 2.11	61.77	68.77	127.95 ± 8.41	110.20	138.87
GFDL	26.7	65.34 ± 3.00	59.78	69.10	124.42 ± 7.61	111.65	140.68
Group 5							
CCC	1.9	61.98 ± 1.14	60.73	63.12	122.29 ± 6.44	113.40	128.25
GFDL	2.1	64.23 ± 0.57	63.32	64.87	120.22 ± 2.97	117.28	126.07
Group 6							
CCC	40.0	63.53 ± 2.09	60.07	66.90	119.30 ± 4.89	110.28	129.48
GFDL	27.9	63.02 ± 1.97	59.83	67.82	118.22 ± 5.45	110.05	129.27
Group 7							
CCC	8.1	65.72 ± 0.43	64.85	66.65	128.13 ± 1.78	124.43	130.70
GFDL	20.6	65.01 ± 2.06	59.78	68.10	122.52 ± 7.48	110.38	134.60

of group 4 may indicate the boundary between mid- and high-Boreal ecoclimatic regions. The absence of projected sites running along a diagonal from southeast to northwest dividing the distribution of that group into two, may mark the separation between the two phases of this group. To the south of the diagonal were low- and mid-Boreal bogs and peat plateaus without permafrost, while to the north were high-Boreal and Subarctic bogs and peat plateaus underlain by permafrost. This apparent division was further enhanced in the CCC scenario by the presence of low-Boreal bogs (group 3) and dry poor fens (group 5) only to the south of the diagonal, and high-Boreal peat plateaus with thermokarst pools (group 2) to the north. That diagonal was also evident in the GFDL scenario where low-Boreal bogs ran exactly along the diagonal and high-Boreal peat plateaus with thermokarst pools parallelled the former but on the north side of the diagonal.

The extant groups 1, 4, and 6 that were widespread throughout most of the Basin, all have similar widespread projected distributions for both scenarios. With the exception of group 6, they generally extended from the projected southern limit of peatlands to the Arctic Ocean. The distribution of groups 6 and 7 which did not reach the northern limit of the Basin was an artifact of the original sampling design translated through the Model. The projected distribution of moderate- and extreme-rich fens likely should be extended to the Arctic Ocean.

This Model projected the distribution of peatlands at equilibrium with the climate as predicted by the climate change scenarios. It was very difficult to determine the lag time between the changes in the vegetation in relation to the new climate. The lag time would probably depend on the type of peatland affected, since some, for example extreme-rich fens, do not have tree growth while others, for example bogs and peat plateaus, have extensive tree growth. Vegetative changes under a warmer drier climate would likely occur much faster in non-treed fens than in treed bogs and peat plateaus. Also influencing lag time will be the size of the peatland, the proportion of the peatland in relationship to the watershed, and the relative position of the peatland in the watershed. Small peatlands will likely be impacted more severely and rapidly than large peatlands. Flow through fens drawing water from a regional source may have a different sensitivity than perched bogs dependant upon precipitation only. Lag time in some peatlands which are fed by larger

more regional sources may be delayed by the residency time of the water moving through the regional aquifer. Residency time in regional aquifers can be in the order of hundreds to thousands of years (Roulet pers. communication), providing a water source long after the surface supply has diminished. The affects of forest fires and its possible reduction on lag time were not explored by the Model.

According to the projected distribution, peatlands would disappear in most areas south of 60° latitude. The nature and type of ecosystem that would replace those peatlands would largely depend on where the peatland was located, the type of water supply for the ecosystem, and the surrounding topography. However, by examining the fossil records of peatlands, it could be possible to determine the type of ecosystem that was originally at the same location and project a reversal of the peat forming processes to produce this original ecosystem. Several alternative results would be possible: 1) areas under peatlands that were originally dry and later paludified may return to a forested status or become grassland; 2) areas that were originally wet, may become marshes dominated by *Typha latifolia and Carex;* or 3) areas where there was a regular supply of water may become ponds, small lakes, or streams. The Model was unable to project which type of ecosystem would replace peatlands after they disappear.

Analogues from the past

The projected northward migration of peatlands as a result of global warming can be corroborated to some extent by pollen records. Temperatures during the mid-Holocene (9000-5000 years B.P.) increased from current temperatures during the growing season by 1.5 °C (Vance 1986) and by as much as 2.5 °C during the month of July (Ritchie and Harrison 1993), resulting in a northward expansion of the parkland-Boreal forest ecotone to somewhere between 54°44'N (Lichti-Federovich 1970, Vance *et al.* 1983), and Mariana Lake, Alberta 55°57'N (Hutton *et al.* 1994). The northern boundary of the Boreal forest also shifted northwards during this time period expanding above current treeline on the Tuktoyaktuk Peninsula, NWT (Ritchie and Hare 1971, Spear 1983), and above current elevations in the Selwyn Mountains, NWT (MacDonald 1983).

Bryophyte dominated peatlands did not exist in western Canada during this time period due to warm and dry climatic conditions (Kuhry *et al.* 1993). Basal dates from peat cores in Alberta indicate that the only regions where peat formation occurred during the early Holocene was on the eastern slopes of the Rocky Mountains and on several northern uplands (Zoltai and Vitt 1990, Halsey *et al.* 1995). As the climate became increasingly moister after 6000 years B.P., extensive peatland development took place expanding peatlands in size (Nicholson and Vitt 1990, 1995), abundance (Hutton *et al.* 1994) and geographical location (Zoltai and Vitt 1990). This is most clearly demonstrated at Mariana Lake where pollen records indicate that peatlands were very abundant in the region early in the Holocene, as early as 10,000 year B.P. and virtually disappeared during the mid-Holocene climatic optimum from 7500 to 5500 years BP (Hutton *et al.* 1994).

Currently the only quantitative estimate of past climate in this region on a mean annual basis comes from Luckman and Kearney (1986) whom investigated oxygen isotopes of subfossil logs above treeline at Maligne Pass in Jasper National Park, Alberta. They indicate that from 5300 to 6000 years B.P. the mean annual temperature increased between 1.2 °C and 1.6 °C. If we assume the same relationships between climate and the position of major ecotones existed in the past as it does today and in the future, then a simple trajectory can be used to compare past climatic conditions against the climate change predictions for the geographical location of the parkland-Boreal forest boundary. Using an average of Luckman and Keaney's (1986) estimates of the increase in mean annual temperatures during the mid-Holocene (1.4 °C), combined with the estimate of the position of the parkland-Boreal forest boundary (55° latitude) as cited above, results in a 1.7 °C increase in latitude with every one degree increase in temperature (**Figure 6**). Continuing along this projection would place the parkland-Boreal forest boundary with a 5 °C increase in temperature at 59°30' latitude. This projection is very comparable to the anticipated position of the boundary predicted by the Model using both the CCC and GFDL climate change scenarios.

Effects on peatland hydrology

South of 60° latitude, where peatlands were predicted to disappear as a result of climate change (**Figure 3b**), mean minimum water table drawdowns shown on **Figure 5** and listed in **Appendix 1** depended on the original water levels in extant peatlands. In areas close to the southern boundaries of the Basin, peatlands were on average drier and water tables were lower relative to the peat surface than those on peatlands located closer to 60° latitude. Since water tables could no longer be tracked by the Model when the water table dropped below 8 dm, the indicated changes in water levels were lower in the areas closer to the southern boundary of the Basin. These results appear to be paradoxical because changes in water levels were smaller

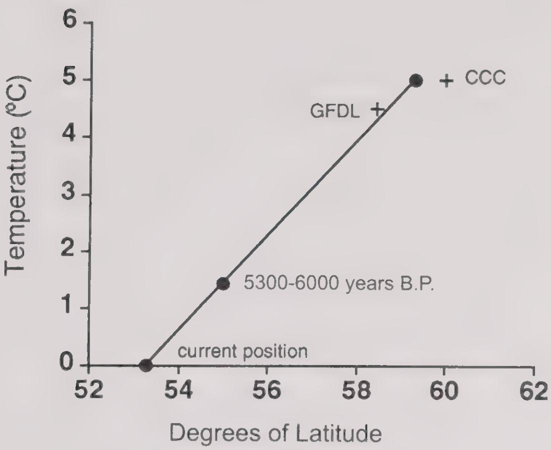


Figure 6. Trajectory of the latitudinal position of the parkland-Boreal forest boundary under a 5°C increase in temperature based on its northward migration during the mid-Holocene. Circles designate its position at current, during the mid-Holocene, and with a 5°C increase. Crosses mark the anticipated position of the boundary based on our projections using the CCC and the GFDL models.

in areas that were predicted by the CCC GCM to have warmer temperatures than areas closer to 60° latitude that were predicted to have slightly cooler temperatures. However, it must be stressed that predicted changes were minimal and total changes in water level could be much greater in southern areas. Since peatlands were predicted to disappear in those areas, the total change in water table depth would depend on the original depth of peat on each site. Thus, sites having depths of peat between 5 and 10 dm would have a small total change in water table depth while sites having up to 3 and 4 m of peat would have total water level changes of several metres.

Drawdowns of the magnitude projected south of 60° latitude (**Figure 5**) are analogous to those encountered when peatlands are drained for forestry or agricultural purposes. Draining peatlands for forestry produced drawdowns of 2.5 to 8.0 dm that resulted in: 1) cessation in the upward growth of the mires; 2) collapse and compression of the peat by 0.7 to 7dm; 3) increased thickness of the peat exposed to the air (Laine and Vanha-Majamaa 1992, Laine *et al.* 1995); and 4) increased temperatures with depth (Leiffers 1988). These changes resulted in loss of peat caused by increased microbial decomposition. The effects described were caused only by drawdown and did not account for increases in temperature caused by climate change. Increased temperatures would enhance the effect of drawdown by accelerating the rate of oxidation of the peat thus reducing its thickness and its insulating effect on evapotranspiration. As a result, unlike peatlands drained for forestry, water tables would continue to drawdown until the peat was completely oxidized.

Effects of drawdown on vegetation in drained peatlands were particularly important in rich fens and, because of nutrient limitations, to a lesser extent in ombrotrophic bogs Some of these effects were: 1) a rapid disappearance of wet species followed by an equally rapid increase in peatland shrub growth; 2) an increase in tree growth that produced more shading; 3) replacement of peatland shrub and bryophyte species by species dominant in the surrounding forests (Laine *et al.* 1995) or grasslands (Francez and Vassander 1995, Nykanen *et al.* 1995). The replacement of peatland bryophytes by species dominant in the surrounding vegetation indicated that the peatland vegetation no longer responded to the water table.

North of 60° latitude where peatlands were predicted to persist at $2XCO_2$ (**Figure 3**), changes in peatland hydrology indicated changes in peatland types. Thus, decreases in water table depths south of Great Bear Lake (63° latitude) at $2XCO_2$ were caused by changes from peat plateaus with thermokarst pools to bogs, dry poor fens, and rich fens that have relatively lower water tables. Peatlands west of Great Bear Lake (between 63° and 65° latitude) that had water tables closer to the peat surface, would change from bogs and peat plateaus underlain by permafrost to peatlands having extensive thermokarst features (Gorham 1991, 1994). Water tables closer to the peat surface in those areas would thus indicate substantial losses of permafrost. North of 65° latitude, water table depths would essentially remain the same with only a slight drying caused by climate change indicating that permafrost will persist in those areas.

Conclusions

The northward migration of the southern boundary of peatland ecosystems as a result of global warming would involve a displacement of approximately 780 km from an area just south of the Mackenzie River Basin to 60° latitude. The extant southern limit of peatlands almost coincides with the southern limit of the Boreal Forest in western Canada. It may be possible to extrapolate those results and project the southern limit of the Boreal Forest to an area straddling 60° latitude. Furthermore, low- and mid-Boreal peatlands were bounded to the north by a diagonal running from south east to northwest through the Basin

from 60° latitude to an area just south of the Mackenzie delta. This would suppose that the low- and mid-Boreal ecoclimatic regions would follow the same patterns. It is anticipated that under climate change the diversity currently seen within the peatlands will be maintained and the most common peatland type would continue to be the moderate-rich fen.

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Appendix 1

Height of the water table relative to the peat surface (dm) + standard deviation (STD) for localities in the Mackenzie River Basin at $1XCO_2$ and $2XCO_2$ based on the CCC climate change scenario. LATD = latitude (degrees). LATM = latitude (minutes). LOND = longitude (degrees). LONM = longitude minutes.

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
1	53	0	116	41	2.5	0.7	8.0	0.0	-5.5	0.7
2	53	1	116	12	2.8	1.1	8.0	0.0	-5.3	1.1
3	53	14	118	12	2.5	0.7	8.0	0.0	-5.5	0.7
4	53	15	117	42	2.5	0.7	8.0	0.0	-5.5	0.7
5	53	16	117	13	2.8	1.1	8.0	0.0	-5.3	1.1
6	53	18	116	43	2.0	0.0	8.0	0.0	-6.0	0.0
7	53	19	116	13	2.8	1.1	8.0	0.0	-5.3	1.1
8	53	32	118	14	2.8	1.1	8.0	0.0	-5.3	1.1
9	53	33	117	44	2.0	0.0	8.0	0.0	-6.0	0.0
10	53	34	117	15	2.3	0.4	8.0	0.0	-5.8	0.4
11	53	35	116	45	3.3	1.1	8.0	0.0	-4.8	1.1
12	53	36	116	15	2.8	1.1	8.0	0.0	-5.3	1.1
13	53	49	118	17	3.3	0.4	8.0	0.0	-4.8	0.4
14	53	50	117	47	2.8	1.1	8.0	0.0	-5.3	1.1
15	53	52	117	16	3.3	1.1	8.0	0.0	-4.8	1.1
16	53	53	116	46	3.3	1.1	8.0	0.0	-4.8	1.1
17	53	54	116	16	2.8	1.1	8.0	0.0	-5.3	1.1
18	54	5	118	49	3.5	0.0	8.0	0.0	-4.5	0.0
19	54	7	118	19	3.3	1.1	8.0	0.0	-4.8	1.1
20	54	8	117	49	2.5	0.7	8.0	0.0	-5.5	0.7
21	54	9	117	18	2.5	0.7	8.0	0.0	-5.5	0.7
22	54	10	116	48	2.5	0.7	8.0	0.0	-5.5	0.7
23	54	11	116	18	2.5	0.7	8.0	0.0	-5.5	0.7
24	54	12	115	47	2.5	0.7	8.0	0.0	-5.5	0.7
25	54	13	115	17	2.0	0.0	8.0	0.0	-6.0	0.0
26	54	14	111	13	2.0	0.0	8.0	0.0	-6.0	0.0
27	54	14	113	46	2.0	0.0	8.0	0.0	-6.0	0.0
28	54	15	111	44	2.3	0.4	8.0	0.0	-5.8	0.4
29	54	15	113	15	2.0	0.0	8.0	0.0	-6.0	0.0
30	54	21	119	22	4.5	1.4	8.0	0.0	-3.5	1.4
31	54	23	118	52	2.8	1.1	8.0	0.0	-5.3	1.1
32	54	24	118	21	3.0	1.4	8.0	0.0	-5.0	1.4
33	54	26	117	51	2.5	0.7	8.0	0.0	-5.5	0.7
34	54	27	117	20	2.0	0.0	8.0	0.0	-6.0	0.0
35	54	28	116	50	2.0	0.0	8.0	0.0	-6.0	0.0
36	54	29	116	19	2.0	0.0	8.0	0.0	-6.0	0.0
37	54	30	115	18	2.0	0.0	8.0	0.0	-6.0	0.0
38	54	30	115	49	2.0	0.0	8.0	0.0	-6.0	0.0
39	54	31	114	17	2.0	0.0	8.0	0.0	-6.0	0.0
40	54	31	114	47	2.0	0.0	8.0	0.0	-6.0	0.0
41	54	32	111	13	2.0	0.0	8.0	0.0	-6.0	0.0
42	54	32	111	44	2.3	0.4	8.0	0.0	-5.8	0.4
43	54	32	113	15	3.3	1.1	8.0	0.0	-4.8	1.1
44	54	32	113	46	3.3	1.1	8.0	0.0	-4.8	1.1
45	54	37	119	56	4.5	1.4	8.0	0.0	-3.5	1.4
46	54	39	119	25	2.8	1.1	8.0	0.0	-5.3	1.1
47	54	40	118	54	3.0	1.4	8.0	0.0	-5.0	1.4
48	54	42	118	24	2.0	0.0	8.0	0.0	-6.0	0.0
49	54	43	117	53	2.0	0.0	8.0	0.0	-6.0	0.0
50	54	44	117	22	2.0	0.0	8.0	0.0	-6.0	0.0
51	54	45	116	52	2.0	0.0	8.0	0.0	-6.0	0.0

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
52	54	46	116	21	2.0	0.0	8.0	0.0	-6.0	0.0
53	54	47	115	50	2.0	0.0	8.0	0.0	-6.0	0.0
54	54	48	115	19	2.0	0.0	8.0	0.0	-6.0	0.0
55	54	49	111	12	2.0	0.0	8.0	0.0	-6.0	0.0
56	54	49	113	47	3.3	1.1	8.0	0.0	-4.8	1.1
57	54	49	114	18	3.3	1.1	8.0	0.0	-4.8	1.1
58	54	49	114	48	2.0	0.0	8.0	0.0	-6.0	0.0
59	54	50	111	43	2.0	0.0	8.0	0.0	-6.0	0.0
60	54	50	113	16	3.3	1.1	8.0	0.0	-4.8	1.1
61	54	53	120	29	4.5	1.4	8.0	0.0	-3.5	1.4
62	54	54	119	59	2.8	1.1	8.0	0.0	-5.3	1.1
63	54	56	119	28	3.3	1.1	8.0	0.0	-4.8	1.1
64	54	58	118	57	2.0	0.0	8.0	0.0	-6.0	0.0
65	54	59	118	26	2.0	0.0	8.0	0.0	-6.0	0.0
66	55	1	117	55	1.8	1.1	8.0	0.0	-6.3	1.1
67	55	2	117	24	2.3	0.4	8.0	0.0	-5.8	0.4
68	55	3	116	53	2.3	0.4	8.0	0.0	-5.8	0.4
69	55	4	116	22	1.8	1.1	8.0	0.0	-6.3	1.1
70	55	5	115	51	1.8	1.1	8.0	0.0	-6.3	1.1
71	55	6	110	10	2.3	0.4	8.0	0.0	-5.8	0.4
72	55	6	114	49	1.8	1.1	8.0	0.0	-6.3	1.1
73	55	6	115	20	1.8	1.1	8.0	0.0	-6.3	1.1
74	55	7	110	41	2.3	0.4	8.0	0.0	-5.8	0.4
75	55	7	111	12	1.8	1.1	8.0	0.0	-6.3	1.1
76	55	7	111	43	1.8	1.1	8.0	0.0	-6.3	1.1
77	55	7	112	14	1.8	1.1	8.0	0.0	-6.3	1.1
78	55	7	112	45	1.8	1.1	8.0	0.0	-6.3	1.1
79	55	7	113	16	1.8	1.1	8.0	0.0	-6.3	1.1
80	55	7	113	47	2.0	0.0	8.0	0.0	-6.0	0.0
81	55	7	114	18	1.8	1.1	8.0	0.0	-6.3	1.1
82	55	10	120	33	2.5	0.7	8.0	0.0	-5.5	0.7
83	55	12	120	2	2.5	0.7	8.0	0.0	-5.5	0.7
84	55	14	119	31	2.0	1.4	8.0	0.0	-6.0	1.4
85	55	15	119	0	1.8	1.1	8.0	0.0	-6.3	1.1
86	55	17	118	29	2.3	0.4	8.0	0.0	-5.8	0.4
87	55	18	117	58	2.3	0.4	8.0	0.0	-5.8	0.4
88	55	19	117	26	2.3	0.4	8.0	0.0	-5.8	0.4
89	55	20	116	55	2.3	0.4	8.0	0.0	-5.8	0.4
90	55	21	116	24	2.3	0.4	8.0	0.0	-5.8	0.4
91	55	22	115	53	2.3	0.4	8.0	0.0	-5.8	0.4
92	55	23	115	22	1.8	1.1	8.0	0.0	-6.3	1.1
93	55	24	110	9	2.3	0.4	8.0	0.0	-5.8	0.4
94	55	24	110	40	2.3	0.4	8.0	0.0	-5.8	0.4
95	55	24	114	19	1.8	1.1	8.0	0.0	-6.3	1.1
96	55	24	114	50	1.8	1.1	8.0	0.0	-6.3	1.1
97	55	25	111	11	1.0	0.0	8.0	0.0	-7.0	0.0
98	55	25	111	43	1.0	0.0	8.0	0.0	-7.0	0.0
99	55	25	112	14	1.8	1.1	8.0	0.0	-6.3	1.1
100	55	25	112	45	1.8	1.1	8.0	0.0	-6.3	1.1
101	55	25	113	16	1.8	1.1	8.0	0.0	-6.3	1.1
102	55	25	113	48	1.8	1.1	8.0	0.0	-6.3	1.1
103	55	28	120	36	2.0	0.0	8.0	0.0	-6.0	0.0
104	55	29	120	5	1.8	1.1	8.0	0.0	-6.3	1.1
105	55	31	119	34	1.8	1.1	8.0	0.0	-6.3	1.1
106	55	33	119	2	1.8	1.1	8.0	0.0	-6.3	1.1
107	55	34	118	31	1.8	1.1	8.0	0.0	-6.3	1.1
108	55	36	118	0	2.3	0.4	8.0	0.0	-5.8	0.4
109	55	37	117	28	2.3	0.4	8.0	0.0	-5.8	0.4
110	55	40	115	54	2.3	0.4	8.0	0.0	-5.8	0.4
111	55	41	110	8	2.3	0.4	8.0	0.0	-5.8	0.4
112	55	41	114	51	1.8	1.1	8.0	0.0	-6.3	1.1
113	55	41	115	23	2.3	0.4	8.0	0.0	-5.8	0.4
114	55	42	110	39	1.0	0.0	8.0	0.0	-7.0	0.0
115	55	42	111	11	1.0	0.0	8.0	0.0	-7.0	0.0
116	55	42	111	42	1.0	0.0	8.0	0.0	-7.0	0.0
117	55	42	113	17	1.8	1.1	8.0	0.0	-6.3	1.1
118	55	42	113	48	1.8	1.1	8.0	0.0	-6.3	1.1
119	55	42	114	20	1.8	1.1	8.0	0.0	-6.3	1.1
120	55	43	112	14	1.0	0.0	8.0	0.0	-7.0	0.0
121	55	43	112	45	1.0	0.0	8.0	0.0	-7.0	0.0
122	55	45	120	39	1.5	0.7	8.0	0.0	-6.5	0.7
123	55	47	120	8	1.0	0.0	8.0	0.0	-7.0	0.0
124	55	49	119	37	1.8	1.1	8.0	0.0	-6.3	1.1
125	55	50	119	5	1.8	1.1	8.0	0.0	-6.3	1.1
126	55	52	118	34	1.8	1.1	8.0	0.0	-6.3	1.1
127	55	53	118	2	2.3	0.4	8.0	0.0	-5.8	0.4
128	55	54	117	31	2.3	0.4	8.0	0.0	-5.8	0.4
129	55	57	115	56	2.5	0.0	8.0	0.0	-5.5	0.0
130	55	58	115	24	2.5	0.0	8.0	0.0	-5.5	0.0
131	55	59	110	7	1.8	1.1	8.0	0.0	-6.3	1.1
132	55	59	110	38	1.0	0.0	8.0	0.0	-7.0	0.0
133	55	59	114	21	1.0	0.0	8.0	0.0	-7.0	0.0
134	55	59	114	52	2.3	0.4	8.0	0.0	-5.8	0.4
135	56	0	111	10	2.3	0.4	8.0	0.0	-5.8	0.4
136	56	0	111	42	2.3	0.4	8.0	0.0	-5.8	0.4
137	56	0	112	14	2.3	0.4	8.0	0.0	-5.8	0.4
138	56	0	112	45	2.3	0.4	8.0	0.0	-5.8	0.4
139	56	0	113	17	2.3	0.4	8.0	0.0	-5.8	0.4
140	56	0	113	49	2.3	0.4	8.0	0.0	-5.8	0.4
141	56	2	120	43	1.8	1.1	8.0	0.0	-6.3	1.1
142	56	4	120	11	2.3	0.4	8.0	0.0	-5.8	0.4
143	56	13	117	1	3.8	0.4	8.0	0.0	-4.3	0.4
144	56	14	116	29	3.8	0.4	8.0	0.0	-4.3	0.4
145	56	15	115	57	3.8	0.4	8.0	0.0	-4.3	0.4
146	56	16	110	6	2.5	0.0	8.0	0.0	-5.5	0.0
147	56	16	115	25	3.8	0.4	8.0	0.0	-4.3	0.4
148	56	17	110	38	2.5	0.0	8.0	0.0	-5.5	0.0
149	56	17	111	10	2.3	0.4	8.0	0.0	-5.8	0.4
150	56	17	111	42	2.3	0.4	8.0	0.0	-5.8	0.4
151	56	17	113	17	2.3	0.4	8.0	0.0	-5.8	0.4
152	56	17	113	49	2.5	0.0	8.0	0.0	-5.5	0.0
153	56	17	114	21	2.5	0.0	8.0	0.0	-5.5	0.0
154	56	18	112	14	2.3	0.4	8.0	0.0	-5.8	0.4
155	56	18	112	45	2.3	0.4	8.0	0.0	-5.8	0.4
156	56	20	120	46	2.3	0.4	8.0	0.0	-5.8	0.4
157	56	24	119	43	2.5	0.0	8.0	0.0	-5.5	0.0
158	56	29	117	35	3.8	0.4	8.0	0.0	-4.3	0.4
159	56	31	117	3	3.8	0.4	8.0	0.0	-4.3	0.4
160	56	32	115	59	3.8	0.4	8.0	0.0	-4.3	0.4
161	56	32	116	31	3.8	0.4	8.0	0.0	-4.3	0.4
162	56	33	115	26	3.8	0.4	8.0	0.0	-4.3	0.4
163	56	34	110	5	1.8	1.1	8.0	0.0	-6.3	1.1
164	56	34	110	37	1.8	1.1	8.0	0.0	-6.3	1.1
165	56	34	114	22	2.5	0.0	8.0	0.0	-5.5	0.0
166	56	35	111	9	2.3	0.4	8.0	0.0	-5.8	0.4
167	56	35	111	41	2.3	0.4	8.0	0.0	-5.8	0.4
168	56	35	112	13	2.3	0.4	8.0	0.0	-5.8	0.4
169	56	35	112	46	2.3	0.4	8.0	0.0	-5.8	0.4
170	56	35	113	18	2.3	0.4	8.0	0.0	-5.8	0.4
171	56	35	113	50	2.5	0.0	8.0	0.0	-5.5	0.0
172	56	37	120	50	2.3	0.4	8.0	0.0	-5.8	0.4
173	56	43	119	14	3.8	0.4	8.0	0.0	-4.3	0.4
174	56	44	118	41	3.8	0.4	8.0	0.0	-4.3	0.4
175	56	46	118	9	3.8	0.4	8.0	0.0	-4.3	0.4
176	56	47	117	37	3.8	0.4	8.0	0.0	-4.3	0.4
177	56	48	117	5	3.8	0.4	8.0	0.0	-4.3	0.4
178	56	49	116	32	3.8	0.4	8.0	0.0	-4.3	0.4
179	56	50	116	0	3.8	0.4	8.0	0.0	-4.3	0.4
180	56	51	110	4	1.8	1.1	8.0	0.0	-6.3	1.1
181	56	51	114	55	3.8	0.4	8.0	0.0	-4.3	0.4

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
182	56	51	115	28	3.8	0.4	8.0	0.0	-4.3	0.4
183	56	52	110	36	1.8	1.1	8.0	0.0	-6.3	1.1
184	56	52	111	8	1.8	1.1	8.0	0.0	-6.3	1.1
185	56	52	113	51	2.5	0.0	8.0	0.0	-5.5	0.0
186	56	53	111	41	1.8	1.1	8.0	0.0	-6.3	1.1
187	56	53	112	13	1.8	1.1	8.0	0.0	-6.3	1.1
188	56	53	112	46	1.8	1.1	8.0	0.0	-6.3	1.1
189	56	53	113	18	1.8	1.1	8.0	0.0	-6.3	1.1
190	56	58	119	49	3.8	0.4	8.0	0.0	-4.3	0.4
191	57	2	118	44	3.5	0.0	8.0	0.0	-4.5	0.0
192	57	3	118	12	3.5	0.0	8.0	0.0	-4.5	0.0
193	57	4	117	39	3.8	0.4	8.0	0.0	-4.3	0.4
194	57	5	117	7	3.8	0.4	8.0	0.0	-4.3	0.4
195	57	5	122	34	2.0	0.0	8.0	0.0	-6.0	0.0
196	57	7	116	2	3.8	0.4	8.0	0.0	-4.3	0.4
197	57	7	116	34	3.8	0.4	8.0	0.0	-4.3	0.4
198	57	8	115	29	3.5	0.0	8.0	0.0	-4.5	0.0
199	57	8	122	2	1.5	0.7	8.0	0.0	-6.5	0.7
200	57	9	110	35	2.5	2.1	8.0	0.0	-5.5	2.1
201	57	9	114	24	2.3	1.8	8.0	0.0	-5.8	1.8
202	57	9	114	56	1.0	.	8.0	.	-7.0	.
203	57	10	111	8	2.3	1.8	8.0	0.0	-5.8	1.8
204	57	10	111	41	2.5	2.1	8.0	0.0	-5.5	2.1
205	57	10	112	13	2.5	2.1	8.0	0.0	-5.5	2.1
206	57	10	112	46	2.5	2.1	8.0	0.0	-5.5	2.1
207	57	10	113	18	2.3	1.8	8.0	0.0	-5.8	1.8
208	57	10	113	51	2.3	1.8	8.0	0.0	-5.8	1.8
209	57	10	121	30	2.0	1.4	8.0	0.0	-6.0	1.4
210	57	12	120	57	3.8	0.4	8.0	0.0	-4.3	0.4
211	57	14	120	25	2.3	1.8	8.0	0.0	-5.8	1.8
212	57	17	119	20	3.5	0.0	8.0	0.0	-4.5	0.0
213	57	19	118	47	3.8	0.4	8.0	0.0	-4.3	0.4
214	57	20	118	14	3.8	0.4	8.0	0.0	-4.3	0.4
215	57	22	117	41	3.0	0.7	8.0	0.0	-5.0	0.7
216	57	23	117	9	3.0	0.7	8.0	0.0	-5.0	0.7
217	57	23	122	39	2.0	1.4	8.0	0.0	-6.0	1.4
218	57	24	116	36	3.5	0.7	8.0	0.0	-4.5	0.7
219	57	25	116	3	3.8	0.4	8.0	0.0	-4.3	0.4
220	57	25	122	6	2.0	1.4	8.0	0.0	-6.0	1.4
221	57	26	114	57	2 3	1.8	8.0	0.0	-5.8	1.8
222	57	26	115	30	3.5	0.0	8.0	0.0	-4.5	0.0
223	57	27	111	7	2.5	2.1	8.0	0.0	-5.5	2.1
224	57	27	113	52	2.3	1.8	8.0	0.0	-5.8	1.8
225	57	27	114	25	2.3	1.8	8.0	0.0	-5.8	1.8
226	57	27	121	34	3.5	0.7	8.0	0.0	-4.5	0.7
227	57	28	111	40	2.5	2.1	8.0	0.0	-5.5	2.1
228	57	28	112	13	2.5	2.1	8.0	0.0	-5.5	2.1
229	57	28	112	46	2.5	2.1	8.0	0.0	-5.5	2.1
230	57	28	113	19	2.5	2.1	8.0	0.0	-5.5	2.1
231	57	29	121	1	2.3	1.8	8.0	0.0	-5.8	1.8
232	57	31	120	28	1.0	0.0	8.0	0.0	-7.0	0.0
233	57	33	119	55	3.8	0.4	8.0	0.0	-4.3	0.4
234	57	35	119	22	3.8	0.4	8.0	0.0	-4.3	0.4
235	57	36	118	50	3.0	0.7	8.0	0.0	-5.0	0.7
236	57	38	118	17	3.0	0.7	8.0	0.0	-5.0	0.7
237	57	39	117	44	3.0	0.7	8.0	0.0	-5.0	0.7
238	57	40	117	11	3.0	0.7	8.0	0.0	-5.0	0.7
239	57	40	122	43	3.3	0.4	8.0	0.0	-4.8	0.4
240	57	41	116	38	3.0	0.7	8.0	0.0	-5.0	0.7
241	57	42	116	5	3.0	0.7	8.0	0.0	-5.0	0.7
242	57	42	122	10	3.0	.	8.0	.	-5.0	.
243	57	43	115	32	3.5	0.0	8.0	0.0	-4.5	0.0
244	57	44	110	0	2.3	1.8	8.0	0.0	-5.8	1.8
245	57	44	110	34	2.3	1.8	8.0	0.0	-5.8	1.8
246	57	44	114	59	2.3	1.8	8.0	0.0	-5.8	1.8

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
247	57	45	112	13	2.5	2.1	8.0	0.0	-5.5	2.1
248	57	45	112	46	2.5	2.1	8.0	0.0	-5.5	2.1
249	57	45	113	19	2.5	2.1	8.0	0.0	-5.5	2.1
250	57	45	113	52	2.5	2.1	8.0	0.0	-5.5	2.1
251	57	45	121	37	2.3	1.8	8.0	0.0	-5.8	1.8
252	57	47	121	5	2.3	1.8	8.0	0.0	-5.8	1.8
253	57	49	120	32	1.0	0.0	8.0	0.0	-7.0	0.0
254	57	51	119	59	3.5	0.0	8.0	0.0	-4.5	0.0
255	57	52	119	26	3.0	0.7	8.0	0.0	-5.0	0.7
256	57	54	118	52	3.0	0.7	8.0	0.0	-5.0	0.7
257	57	55	118	19	3.0	0.7	8.0	0.0	-5.0	0.7
258	57	57	117	46	3.0	0.7	8.0	0.0	-5.0	0.7
259	57	57	122	48	3.0	.	8.0	.	-5.0	.
260	57	58	117	13	3.0	0.7	8.0	0.0	-5.0	0.7
261	57	59	116	40	2.8	1.1	8.0	0.0	-5.3	1.1
262	58	0	116	6	3.5	0.7	8.0	0.0	-4.5	0.7
263	58	0	122	15	1.8	1.1	8.0	0.0	-6.3	1.1
264	58	1	115	0	1.8	1.1	8.0	0.0	-6.3	1.1
265	58	2	110	33	2.5	2.1	8.0	0.0	-5.5	2.1
266	58	2	111	6	2.3	1.8	8.0	0.0	-5.8	1.8
267	58	2	111	39	2.3	1.8	8.0	0.0	-5.8	1.8
268	58	2	113	20	1.8	1.1	8.0	0.0	-6.3	1.1
269	58	2	113	53	1.8	1.1	8.0	0.0	-6.3	1.1
270	58	2	114	26	1.8	1.1	8.0	0.0	-6.3	1.1
271	58	2	121	42	2.3	0.4	8.0	0.0	-5.8	0.4
272	58	3	112	13	2.3	1.8	8.0	0.0	-5.8	1.8
273	58	3	112	46	1.8	1.1	8.0	0.0	-6.3	1.1
274	58	4	121	8	2.5	0.0	8.0	0.0	-5.5	0.0
275	58	8	120	2	3.8	0.4	8.0	0.0	-4.3	0.4
276	58	10	119	29	3.8	0.4	8.0	0.0	-4.3	0.4
277	58	11	118	55	3.5	0.7	8.0	0.0	-4.5	0.7
278	58	13	118	22	3.8	0.4	8.0	0.0	-4.3	0.4
279	58	14	117	48	3.8	0.4	8.0	0.0	-4.3	0.4
280	58	15	117	15	3.5	0.7	8.0	0.0	-4.5	0.7
281	58	15	122	52	1.0	0.0	8.0	0.0	-7.0	0.0
282	58	16	116	41	3.5	0.7	8.0	0.0	-4.5	0.7
283	58	17	116	8	3.5	0.7	8.0	0.0	-4.5	0.7
284	58	17	122	19	1.0	0.0	8.0	0.0	-7.0	0.0
285	58	19	110	32	0.5	0.7	8.0	0.0	-7.5	0.7
286	58	19	114	27	2.3	1.8	8.0	0.0	-5.8	1.8
287	58	19	115	1	2.3	1.8	8.0	0.0	-5.8	1.8
288	58	19	121	46	1.8	1.1	8.0	0.0	-6.3	1.1
289	58	20	111	5	0.5	0.7	8.0	0.0	-7.5	0.7
290	58	20	111	39	0.5	0.7	8.0	0.0	-7.5	0.7
291	58	20	112	46	3.5	.	8.0	.	-4.5	.
292	58	20	113	20	1.8	2.5	8.0	0.0	-6.3	2.5
293	58	20	113	54	1.8	2.5	8.0	0.0	-6.3	2.5
294	58	21	121	12	1.8	1.1	8.0	0.0	-6.3	1.1
295	58	25	120	5	3.5	0.7	8.0	0.0	-4.5	0.7
296	58	27	119	32	3.5	0.7	8.0	0.0	-4.5	0.7
297	58	29	118	58	3.5	0.7	8.0	0.0	-4.5	0.7
298	58	30	118	24	3.8	0.4	8.0	0.0	-4.3	0.4
299	58	31	117	51	3.5	0.7	8.0	0.0	-4.5	0.7
300	58	32	122	57	3.0	.	8.0	.	-5.0	.
301	58	33	117	17	1.0	0.0	8.0	0.0	-7.0	0.0
302	58	34	116	43	1.0	0.0	8.0	0.0	-7.0	0.0
303	58	34	122	23	3.0	.	8.0	.	-5.0	.
304	58	35	115	36	1.0	.	8.0	.	-7.0	.
305	58	35	116	10	1.0	0.0	8.0	0.0	-7.0	0.0
306	58	36	115	2	1.8	2.5	8.0	0.0	-6.3	2.5
307	58	37	110	31	0.5	0.7	8.0	0.0	-7.5	0.7
308	58	37	111	5	0.5	0.7	8.0	0.0	-7.5	0.7
309	58	37	111	39	0.5	0.7	8.0	0.0	-7.5	0.7
310	58	37	112	13	0.5	0.7	8.0	0.0	-7.5	0.7
311	58	37	112	46	0.5	0.7	8.0	0.0	-7.5	0.7

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
312	58	37	113	20	0.5	0.7	8.0	0.0	-7.5	0.7
313	58	37	121	50	2.3	1.8	8.0	0.0	-5.8	1.8
314	58	39	121	16	2.3	1.8	8.0	0.0	-5.8	1.8
315	58	43	120	9	1.0	0.0	8.0	0.0	-7.0	0.0
316	58	44	119	35	1.0	0.0	8.0	0.0	-7.0	0.0
317	58	46	119	1	1.0	0.0	8.0	0.0	-7.0	0.0
318	58	48	118	27	0.5	0.7	8.0	0.0	-7.5	0.7
319	58	49	117	53	0.5	0.7	8.0	0.0	-7.5	0.7
320	58	50	117	19	0.5	0.7	8.0	0.0	-7.5	0.7
321	58	51	116	45	0.5	0.7	8.0	0.0	-7.5	0.7
322	58	52	116	11	0.5	0.7	8.0	0.0	-7.5	0.7
323	58	52	122	28	2.3	1.8	8.0	0.0	-5.8	1.8
324	58	53	115	37	0.5	0.7	8.0	0.0	-7.5	0.7
325	58	54	110	30	3.5	0.7	8.0	0.0	-4.5	0.7
326	58	54	114	29	0.5	0.7	8.0	0.0	-7.5	0.7
327	58	54	115	3	0.5	0.7	8.0	0.0	-7.5	0.7
328	58	54	121	54	2.3	1.8	8.0	0.0	-5.8	1.8
329	58	55	111	4	3.5	0.7	8.0	0.0	-4.5	0.7
330	58	55	111	38	0.5	0.7	8.0	0.0	-7.5	0.7
331	58	55	112	12	0.5	0.7	8.0	0.0	-7.5	0.7
332	58	55	112	47	0.5	0.7	8.0	0.0	-7.5	0.7
333	58	55	113	21	0.5	0.7	8.0	0.0	-7.5	0.7
334	58	55	113	55	0.5	0.7	8.0	0.0	-7.5	0.7
335	58	56	121	20	1.0	0.0	8.0	0.0	-7.0	0.0
336	58	58	120	46	0.5	0.7	8.0	0.0	-7.5	0.7
337	59	0	120	12	2.0	1.4	8.0	0.0	-6.0	1.4
338	59	2	119	38	2.0	1.4	8.0	0.0	-6.0	1.4
339	59	3	119	4	2.0	1.4	8.0	0.0	-6.0	1.4
340	59	5	118	30	2.0	1.4	8.0	0.0	-6.0	1.4
341	59	6	117	56	2.0	1.4	8.0	0.0	-6.0	1.4
342	59	7	117	21	2.0	1.4	8.0	0.0	-6.0	1.4
343	59	9	116	13	2.5	2.1	8.0	0.0	-5.5	2.1
344	59	9	116	47	2.5	2.1	8.0	0.0	-5.5	2.1
345	59	9	122	32	2.5	2.1	8.0	0.0	-5.5	2.1
346	59	10	115	39	2.5	2.1	8.0	0.0	-5.5	2.1
347	59	11	115	4	2.5	2.1	8.0	0.0	-5.5	2.1
348	59	12	110	29	1.0	0.0	8.0	0.0	-7.0	0.0
349	59	12	111	4	1.0	0.0	8.0	0.0	-7.0	0.0
350	59	12	111	38	1.0	0.0	8.0	0.0	-7.0	0.0
351	59	12	112	12	1.0	0.0	8.0	0.0	-7.0	0.0
352	59	12	112	47	1.0	0.0	8.0	0.0	-7.0	0.0
353	59	12	113	21	2.0	1.4	8.0	0.0	-6.0	1.4
354	59	12	113	55	2.0	1.4	8.0	0.0	-6.0	1.4
355	59	12	114	30	2.5	2.1	8.0	0.0	-5.5	2.1
356	59	13	121	24	2.5	2.1	8.0	0.0	-5.5	2.1
357	59	15	120	50	2.0	1.4	8.0	0.0	-6.0	1.4
358	59	17	120	16	2.0	1.4	8.0	0.0	-6.0	1.4
359	59	19	119	41	2.0	1.4	8.0	0.0	-6.0	1.4
360	59	21	119	7	2.0	1.4	8.0	0.0	-6.0	1.4
361	59	22	118	33	2.0	1.4	8.0	0.0	-6.0	1.4
362	59	24	117	58	2.0	1.4	8.0	0.0	-6.0	1.4
363	59	25	117	24	2.0	1.4	8.0	0.0	-6.0	1.4
364	59	26	116	49	2.5	2.1	8.0	0.0	-5.5	2.1
365	59	26	122	37	2.5	2.1	8.0	0.0	-5.5	2.1
366	59	27	116	15	2.5	2.1	8.0	0.0	-5.5	2.1
367	59	28	115	5	1.0	0.0	8.0	0.0	-7.0	0.0
368	59	28	115	40	2.5	2.1	8.0	0.0	-5.5	2.1
369	59	28	122	3	2.5	2.1	8.0	0.0	-5.5	2.1
370	59	29	110	28	1.0	0.0	8.0	0.0	-7.0	0.0
371	59	29	111	3	1.0	0.0	8.0	0.0	-7.0	0.0
372	59	29	113	56	1.0	0.0	8.0	0.0	-7.0	0.0
373	59	29	114	31	1.0	0.0	8.0	0.0	-7.0	0.0
374	59	30	111	38	1.0	0.0	8.0	0.0	-7.0	0.0
375	59	30	112	12	1.0	0.0	8.0	0.0	-7.0	0.0
376	59	30	112	47	1.0	0.0	8.0	0.0	-7.0	0.0

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
377	59	30	113	21	1.0	0.0	8.0	0.0	-7.0	0.0
378	59	31	121	28	2.0	1.4	8.0	0.0	-6.0	1.4
379	59	33	120	54	2.0	1.4	8.0	0.0	-6.0	1.4
380	59	35	120	19	2.0	1.4	8.0	0.0	-6.0	1.4
381	59	36	119	45	2.0	1.4	8.0	0.0	-6.0	1.4
382	59	38	119	10	2.0	1.4	8.0	0.0	-6.0	1.4
383	59	40	118	35	2.0	1.4	8.0	0.0	-6.0	1.4
384	59	41	118	1	1.0	0.0	8.0	0.0	-7.0	0.0
385	59	42	117	26	1.0	0.0	8.0	0.0	-7.0	0.0
386	59	43	116	51	1.0	0.0	8.0	0.0	-7.0	0.0
387	59	43	122	42	2.0	1.4	8.0	0.0	-6.0	1.4
388	59	44	116	16	1.0	0.0	8.0	0.0	-7.0	0.0
389	59	45	115	41	1.0	0.0	8.0	0.0	-7.0	0.0
390	59	46	110	27	1.5	0.7	8.0	0.0	-6.5	0.7
391	59	46	114	32	1.0	0.0	8.0	0.0	-7.0	0.0
392	59	46	115	7	1.0	0.0	8.0	0.0	-7.0	0.0
393	59	46	122	7	2.0	1.4	8.0	0.0	-6.0	1.4
394	59	47	111	2	1.5	0.7	8.0	0.0	-6.5	0.7
395	59	47	111	37	1.0	0.0	8.0	0.0	-7.0	0.0
396	59	47	112	12	1.0	0.0	8.0	0.0	-7.0	0.0
397	59	47	112	47	1.0	0.0	8.0	0.0	-7.0	0.0
398	59	47	113	22	1.0	0.0	8.0	0.0	-7.0	0.0
399	59	47	113	57	1.0	0.0	8.0	0.0	-7.0	0.0
400	59	48	121	32	2.0	1.4	8.0	0.0	-6.0	1.4
401	59	50	120	58	2.0	1.4	8.0	0.0	-6.0	1.4
402	59	52	120	23	2.0	1.4	8.0	0.0	-6.0	1.4
403	59	54	119	48	2.0	1.4	8.0	0.0	-6.0	1.4
404	59	55	119	13	1.0	0.0	8.0	0.0	-7.0	0.0
405	59	57	118	38	1.0	0.0	8.0	0.0	-7.0	0.0
406	59	58	118	3	1.0	0.0	8.0	0.0	-7.0	0.0
407	60	0	117	28	2.0	1.4	8.0	0.0	-6.0	1.4
408	60	1	116	53	2.0	1.4	8.0	0.0	-6.0	1.4
409	60	1	122	46	2.0	1.4	8.0	0.0	-6.0	1.4
410	60	2	115	43	1.0	0.0	8.0	0.0	-7.0	0.0
411	60	2	116	18	1.0	0.0	8.0	0.0	-7.0	0.0
412	60	3	115	8	1.0	0.0	8.0	0.0	-7.0	0.0
413	60	3	122	12	2.0	1.4	8.0	0.0	-6.0	1.4
414	60	4	110	26	1.0	0.0	2.8	0.4	-1.8	0.4
415	60	4	111	2	1.0	0.0	3.5	0.0	-2.5	0.0
416	60	4	111	37	1.0	0.0	8.0	0.0	-7.0	0.0
417	60	4	112	12	1.0	0.0	8.0	0.0	-7.0	0.0
418	60	4	112	47	1.0	0.0	8.0	0.0	-7.0	0.0
419	60	4	113	22	1.0	0.0	8.0	0.0	-7.0	0.0
420	60	4	113	58	1.0	0.0	8.0	0.0	-7.0	0.0
421	60	4	114	33	1.0	0.0	8.0	0.0	-7.0	0.0
422	60	5	121	37	2.8	1.1	8.0	0.0	-5.3	1.1
423	60	7	121	2	2.8	1.1	8.0	0.0	-5.3	1.1
424	60	9	120	27	2.0	1.4	8.0	0.0	-6.0	1.4
425	60	11	119	52	2.0	1.4	8.0	0.0	-6.0	1.4
426	60	13	119	16	2.0	1.4	8.0	0.0	-6.0	1.4
427	60	14	118	41	2.0	1.4	8.0	0.0	-6.0	1.4
428	60	16	118	6	1.0	0.0	8.0	0.0	-7.0	0.0
429	60	17	117	31	1.0	0.0	8.0	0.0	-7.0	0.0
430	60	18	116	55	1.0	0.0	8.0	0.0	-7.0	0.0
431	60	18	122	51	2.0	1.4	8.0	0.0	-6.0	1.4
432	60	19	116	20	1.0	0.0	8.0	0.0	-7.0	0.0
433	60	20	115	9	1.5	0.7	8.0	0.0	-6.5	0.7
434	60	20	115	45	1.5	0.7	8.0	0.0	-6.5	0.7
435	60	20	122	16	1.0	0.0	8.0	0.0	-7.0	0.0
436	60	21	110	25	1.5	0.7	3.5	0.0	-2.0	0.7
437	60	21	111	1	1.5	0.7	3.5	0.0	-2.0	0.7
438	60	21	113	58	1.5	0.7	3.3	1.1	-1.8	0.4
439	60	21	114	34	1.5	0.7	8.0	0.0	-6.5	0.7
440	60	22	111	36	1.0	0.0	3.5	0.0	-2.5	0.0
441	60	22	112	12	1.0	0.0	8.0	0.0	-7.0	0.0

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
442	60	22	112	47	1.0	0.0	3.5	0.0	-2.5	0.0
443	60	22	113	23	1.5	0.7	3.5	0.0	-2.0	0.7
444	60	22	121	41	1.0	0.0	8.0	0.0	-7.0	0.0
445	60	24	121	6	1.0	0.0	8.0	0.0	-7.0	0.0
446	60	26	120	30	1.0	0.0	8.0	0.0	-7.0	0.0
447	60	28	119	55	2.0	1.4	8.0	0.0	-6.0	1.4
448	60	30	119	20	1.0	0.0	8.0	0.0	-7.0	0.0
449	60	31	118	44	1.0	0.0	8.0	0.0	-7.0	0.0
450	60	33	118	9	1.0	0.0	8.0	0.0	-7.0	0.0
451	60	34	117	33	1.0	0.0	2.8	0.4	-1.8	0.4
452	60	35	116	57	1.0	0.0	2.8	0.4	-1.8	0.4
453	60	35	122	56	2.0	1.4	3.5	0.0	-1.5	1.4
454	60	36	116	22	1.5	0.7	2.8	0.4	-1.3	0.4
455	60	37	115	46	1.5	0.7	2.8	0.4	-1.3	0.4
456	60	37	122	21	1.0	0.0	2.8	0.4	-1.8	0.4
457	60	38	110	24	2.3	1.8	5.8	3.2	-3.5	1.4
458	60	38	114	35	1.5	0.7	2.8	0.4	-1.3	0.4
459	60	38	115	10	1.5	0.7	2.8	0.4	-1.3	0.4
460	60	39	111	0	1.5	0.7	3.5	0.0	-2.0	0.7
461	60	39	111	36	1.5	0.7	3.5	0.0	-2.0	0.7
462	60	39	112	12	1.5	0.7	3.5	0.0	-2.0	0.7
463	60	39	112	47	1.5	0.7	3.5	0.0	-2.0	0.7
464	60	39	113	23	1.5	0.7	2.8	0.4	-1.3	0.4
465	60	39	113	59	1.5	0.7	2.8	0.4	-1.3	0.4
466	60	40	121	45	1.0	0.0	3.5	0.0	-2.5	0.0
467	60	42	121	10	1.0	0.0	3.5	0.0	-2.5	0.0
468	60	44	120	34	1.0	0.0	3.3	1.1	-2.3	1.1
469	60	45	119	59	1.5	0.7	3.0	0.7	-1.5	0.0
470	60	47	119	23	1.0	0.0	2.8	0.4	-1.8	0.4
471	60	49	118	47	1.0	0.0	2.8	0.4	-1.8	0.4
472	60	50	118	11	1.0	0.0	2.8	0.4	-1.8	0.4
473	60	51	117	35	1.0	0.0	2.8	0.4	-1.8	0.4
474	60	53	117	0	1.5	0.7	2.8	0.4	-1.3	0.4
475	60	54	115	48	1.5	0.7	2.8	0.4	-1.3	0.4
476	60	54	116	24	1.5	0.7	2.8	0.4	-1.3	0.4
477	60	55	115	12	1.5	0.7	2.8	0.4	-1.3	0.4
478	60	55	122	25	2.0	1.4	3.5	0.0	-1.5	1.4
479	60	56	110	23	1.8	2.5	3.8	0.4	-2.0	2.8
480	60	56	110	59	1.8	2.5	3.8	0.4	-2.0	2.8
481	60	56	111	35	2.3	1.8	5.8	3.2	-3.5	1.4
482	60	56	112	11	2.3	1.8	3.8	0.4	-1.5	2.1
483	60	56	112	48	2.3	1.8	3.5	0.0	-1.3	1.8
484	60	56	113	24	2.3	1.8	3.5	0.0	-1.3	1.8
485	60	56	114	0	2.3	1.8	3.5	0.0	-1.3	1.8
486	60	56	114	36	1.5	0.7	2.8	0.4	-1.3	0.4
487	60	57	121	50	1.0	0.0	3.5	0.0	-2.5	0.0
488	60	59	121	14	1.0	0.0	3.5	0.0	-2.5	0.0
489	61	1	120	38	1.5	0.7	3.3	0.4	-1.8	1.1
490	61	3	120	2	2.5	2.1	2.8	0.4	-0.3	1.8
491	61	4	119	26	3.3	1.1	2.8	0.4	0.5	0.7
492	61	6	118	50	3.3	1.1	2.8	0.4	0.5	0.7
493	61	7	118	14	2.5	2.1	2.8	0.4	-0.3	1.8
494	61	7	123	42	0.5	0.7	2.8	0.4	-2.3	1.1
495	61	9	117	38	1.3	1.8	2.8	0.4	-1.5	2.1
496	61	9	123	6	0.5	0.7	3.8	0.4	-3.3	0.4
497	61	10	117	2	1.3	1.8	2.8	0.4	-1.5	2.1
498	61	11	116	25	1.8	1.1	3.5	0.0	-1.8	1.1
499	61	12	115	13	1.8	1.1	3.8	0.4	-2.0	1.4
500	61	12	115	49	1.8	1.1	3.8	0.4	-2.0	1.4
501	61	12	122	30	1.5	0.7	3.3	0.4	-1.8	1.1
502	61	13	110	22	2.0	2.8	4.5	1.4	-2.5	4.2
503	61	13	110	59	2.0	2.8	5.0	2.1	-3.0	4.9
504	61	13	114	0	2.5	2.1	3.8	0.4	-1.3	2.5
505	61	13	114	37	1.0	.	3.5	.	-2.5	.
506	61	14	111	35	2.0	2.8	4.5	1.4	-2.5	4.2

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
507	61	14	112	11	2.0	2.8	4.5	1.4	-2.5	4.2
508	61	14	112	48	2.5	2.1	4.5	1.4	-2.0	3.5
509	61	14	113	24	4.0	.	3.5	.	0.5	.
510	61	14	121	54	1.5	0.7	3.3	0.4	-1.8	1.1
511	61	16	121	18	1.5	0.7	3.3	0.4	-1.8	1.1
512	61	18	120	42	1.5	0.7	3.3	0.4	-1.8	1.1
513	61	20	120	6	2.5	2.1	3.3	0.4	-0.8	2.5
514	61	22	119	29	2.5	2.1	3.5	0.0	-1.0	2.1
515	61	23	118	53	2.5	2.1	2.8	0.4	-0.3	1.8
516	61	24	123	47	0.5	0.7	2.8	0.4	-2.3	1.1
517	61	25	118	17	0.0	.	3.0	.	-3.0	.
518	61	26	117	40	1.3	1.8	2.8	0.4	-1.5	2.1
519	61	26	123	11	0.5	0.7	2.8	0.4	-2.3	1.1
520	61	27	117	4	1.8	1.1	2.8	0.4	-1.0	1.4
521	61	28	116	27	1.8	1.1	3.0	0.7	-1.3	1.8
522	61	29	115	51	2.5	2.1	3.5	0.0	-1.0	2.1
523	61	29	122	35	1.5	0.7	3.8	0.4	-2.3	1.1
524	61	30	110	21	2.0	2.8	1.8	2.5	0.3	0.4
525	61	30	114	38	2.5	2.1	4.5	1.4	-2.0	3.5
526	61	30	115	14	2.5	2.1	3.5	0.0	-1.0	2.1
527	61	31	111	35	2.0	2.8	4.5	1.4	-2.5	4.2
528	61	31	112	11	2.0	2.8	4.5	1.4	-2.5	4.2
529	61	31	112	48	2.0	2.8	4.5	1.4	-2.5	4.2
530	61	31	113	24	2.8	2.5	4.5	1.4	-1.8	3.9
531	61	31	114	1	2.8	2.5	4.5	1.4	-1.8	3.9
532	61	31	121	59	1.5	0.7	3.3	0.4	-1.8	1.1
533	61	33	121	22	1.5	0.7	3.3	0.4	-1.8	1.1
534	61	35	120	46	1.5	0.7	3.3	0.4	-1.8	1.1
535	61	37	120	9	2.5	2.1	3.5	0.0	-1.0	2.1
536	61	39	119	33	4.0	.	3.0	.	1.0	
537	61	40	118	56	1.3	1.8	3.5	0.0	-2.3	1.8
538	61	42	118	20	1.8	1.1	3.5	0.0	-1.8	1.1
539	61	43	117	43	1.8	1.1	3.5	0.0	-1.8	1.1
540	61	43	123	17	0.5	0.7	2.8	0.4	-2.3	1.1
541	61	44	117	6	1.8	1.1	3.5	0.0	-1.8	1.1
542	61	45	116	29	2.5	2.1	3.8	0.4	-1.3	2.5
543	61	46	115	52	2.0	2.8	4.5	1.4	-2.5	4.2
544	61	46	122	40	0.5	0.7	3.8	0.4	-3.3	0.4
545	61	47	110	20	2.5	.	0.0	.	2.5	
546	61	47	114	39	2.0	2.8	4.5	1.4	-2.5	4.2
547	61	47	115	16	2.0	2.8	4.5	1.4	-2.5	4.2
548	61	48	110	57	2.5	.	0.0	.	2.5	
549	61	48	111	34	0.0	.	0.0	.	0.0	
550	61	48	112	11	0.0	.	0.0	.	0.0	.
551	61	48	114	2	2.0	2.8	4.5	1.4	-2.5	4.2
552	61	48	122	3	1.5	0.7	3.3	0.4	-1.8	1.1
553	61	50	121	27	1.5	0.7	3.5	0.0	-2.0	0.7
554	61	52	120	50	1.5	0.7	3.5	0.0	-2.0	0.7
555	61	54	120	13	2.5	2.1	3.5	0.0	-1.0	2.1
556	61	56	119	36	2.5	2.1	3.5	0.0	-1.0	2.1
557	61	58	118	59	1.8	1.1	3.5	0.0	-1.8	1.1
558	61	59	118	22	1.8	1.1	3.5	0.0	-1.8	1.1
559	62	0	117	45	2.0	2.8	3.8	0.4	-1.8	3.2
560	62	0	123	22	0.5	0.7	2.8	0.4	-2.3	1.1
561	62	1	117	8	2.0	2.8	4.5	1.4	-2.5	4.2
562	62	3	115	54	2.0	2.8	4.5	1.4	-2.5	4.2
563	62	3	116	31	2.0	2.8	4.5	1.4	-2.5	4.2
564	62	3	122	45	2.0	.	3.0	.	-1.0	
565	62	5	110	19	3.3	1.1	2.3	1.8	1.0	0.7
566	62	5	110	56	2.5	.	0.0	.	2.5	
567	62	5	111	34	2.5	.	0.0	.	2.5	
568	62	5	113	25	0.0	.	0.0	.	0.0	
569	62	5	122	8	2.0	.	2.5	.	-0.5	
570	62	6	112	11	2.5	.	0.0	.	2.5	
571	62	6	112	48	0.0	.	0.0	.	0.0	

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
572	62	7	121	31	2.0	.	2.5	.	-0.5	.
573	62	9	120	54	1.5	0.7	3.8	0.4	-2.3	0.4
574	62	11	120	17	1.5	2.1	3.5	0.0	-2.0	2.1
575	62	12	124	41	2.3	1.8	2.8	0.4	-0.5	2.1
576	62	13	119	40	1.5	2.1	3.5	0.0	-2.0	2.1
577	62	15	119	3	1.3	1.8	3.8	0.4	-2.5	2.1
578	62	15	124	4	0.5	0.7	2.8	0.4	-2.3	1.1
579	62	16	118	25	2.0	2.8	3.8	0.4	-1.8	3.2
580	62	18	117	48	2.0	2.8	4.5	1.4	-2.5	4.2
581	62	18	123	27	0.5	0.7	2.8	0.4	-2.3	1.1
582	62	19	117	11	2.0	2.8	4.5	1.4	-2.5	4.2
583	62	20	122	50	1.5	0.7	3.3	0.4	-1.8	1.1
584	62	22	114	3	0.0	.	0.0	.	0.0	.
585	62	22	122	13	1.5	0.7	3.3	0.4	-1.8	1.1
586	62	23	112	11	2.5	.	0.0	.	2.5	.
587	62	23	112	48	2.5	.	0.0	.	2.5	.
588	62	23	113	26	0.0	.	0.0	.	0.0	.
589	62	25	121	36	1.5	2.1	3.8	0.4	-2.3	2.5
590	62	26	125	24	3.5	.	3.0	.	0.5	.
591	62	27	120	58	3.5	0.7	3.8	0.4	-0.3	0.4
592	62	29	120	21	1.5	2.1	3.5	0.0	-2.0	2.1
593	62	30	119	43	1.8	2.5	3.8	0.4	-2.0	2.8
594	62	32	119	6	2.0	2.8	3.8	0.4	-1.8	3.2
595	62	32	124	10	0.5	0.7	2.8	0.4	-2.3	1.1
596	62	33	118	28	2.0	2.8	4.5	1.4	-2.5	4.2
597	62	35	117	51	2.0	2.8	2.8	1.1	-0.8	1.8
598	62	35	123	33	0.5	0.7	3.5	0.7	-3.0	0.0
599	62	36	117	13	0.0	.	0.0	.	0.0	.
600	62	37	116	35	0.0	.	0.0	.	0.0	.
601	62	37	122	55	1.5	2.1	3.3	0.4	-1.8	1.8
602	62	37	126	45	3.0	.	3.0	.	0.0	.
603	62	38	115	20	2.5	.	0.0	.	2.5	.
604	62	39	114	42	2.5	.	0.0	.	2.5	.
605	62	39	122	18	1.5	2.1	3.8	0.4	-2.3	2.5
606	62	40	126	8	3.0	.	3.0	.	0.0	.
607	62	42	121	40	3.5	0.7	3.5	0.0	0.0	0.7
608	62	43	125	31	1.8	2.5	2.8	0.4	-1.0	2.8
609	62	44	121	3	3.5	0.7	3.5	0.0	0.0	0.7
610	62	46	120	25	1.8	2.5	3.8	0.4	-2.0	2.8
611	62	46	124	53	0.5	0.7	2.8	0.4	-2.3	1.1
612	62	47	119	47	1.8	2.5	4.5	1.4	-2.8	3.9
613	62	49	119	9	2.0	2.8	5.0	2.1	-3.0	4.9
614	62	49	124	16	0.0	.	3.5	.	-3.5	.
615	62	50	118	31	0.0	.	0.0	.	0.0	.
616	62	50	127	30	3.0	.	3.5	.	-0.5	.
617	62	52	117	53	0.0	.	0.0	.	0.0	.
618	62	52	123	38	1.5	2.1	3.3	0.4	-1.8	1.8
619	62	53	117	15	2.5	.	0.0	.	2.5	.
620	62	54	116	37	2.5	.	0.0	.	2.5	.
621	62	54	123	1	1.5	2.1	3.8	0.4	-2.3	2.5
622	62	54	126	52	3.0	.	3.0	.	0.0	.
623	62	55	115	59	2.5	.	0.0	.	2.5	.
624	62	56	122	23	1.5	2.1	3.5	0.0	-2.0	2.1
625	62	57	126	15	3.0	.	3.0	.	0.0	.
626	62	59	121	45	1.8	2.5	3.8	0.4	-2.0	2.8
627	63	1	121	7	1.8	2.5	3.8	0.4	-2.0	2.8
628	63	3	120	29	1.8	2.5	3.8	0.4	-2.0	2.8
629	63	3	125	0	1.5	2.1	3.5	0.7	-2.0	1.4
630	63	4	119	51	1.8	2.5	5.0	2.1	-3.3	4.6
631	63	6	119	13	2.5	.	0.0	.	2.5	.
632	63	6	124	22	1.5	2.1	3.5	0.7	-2.0	1.4
633	63	8	118	34	2.5	.	0.0	.	2.5	.
634	63	8	123	44	1.5	2.1	3.8	0.4	-2.3	2.5
635	63	9	117	56	2.5	.	0.0	.	2.5	.
636	63	10	117	18	2.5	.	0.0	.	2.5	.
637	63	10	127	0	3.0	.	3.0	.	0.0	.
638	63	11	116	40	2.5	.	0.0	.	2.5	.
639	63	11	123	6	1.5	2.1	3.5	0.0	-2.0	2.1
640	63	13	122	28	1.8	2.5	3.8	0.4	-2.0	2.8
641	63	14	126	22	0.0	.	3.0	.	-3.0	.
642	63	16	121	50	3.3	1.1	4.5	1.4	-1.3	2.5
643	63	17	125	44	0.0	.	3.0	.	-3.0	.
644	63	18	121	11	3.3	1.1	5.0	2.1	-1.8	3.2
645	63	20	120	33	3.3	1.1	1.8	2.5	1.5	1.4
646	63	20	125	6	3.5	0.7	3.3	0.4	0.3	1.1
647	63	21	119	55	3.3	1.1	1.8	2.5	1.5	1.4
648	63	23	119	16	2.5	.	0.0	.	2.5	.
649	63	23	124	28	1.5	2.1	3.3	0.4	-1.8	1.8
650	63	25	118	38	2.5	.	0.0	.	2.5	.
651	63	25	123	50	1.5	2.1	3.8	0.4	-2.3	2.5
652	63	26	117	59	2.5	.	0.0	.	2.5	.
653	63	28	123	11	3.0	0.7	4.5	1.4	-1.5	2.1
654	63	30	122	33	3.3	1.1	3.8	0.4	-0.5	1.4
655	63	33	121	54	3.3	1.1	1.8	2.5	1.5	1.4
656	63	34	125	51	1.5	2.1	5.0	2.1	-3.5	4.2
657	63	35	121	16	3.3	1.1	1.8	2.5	1.5	1.4
658	63	37	120	37	2.5	.	0.0	.	2.5	.
659	63	37	125	12	1.3	1.8	4.5	1.4	-3.3	3.2
660	63	39	119	58	2.5	.	0.0	.	2.5	.
661	63	40	119	20	2.5	.	0.0	.	2.5	.
662	63	40	124	34	1.3	1.8	3.8	0.4	-2.5	2.1
663	63	42	123	56	2.8	0.4	4.5	1.4	-1.8	1.8
664	63	44	127	15	0.0	.	3.0	.	-3.0	.
665	63	45	123	17	3.3	1.1	4.5	1.4	-1.3	2.5
666	63	47	122	38	3.3	1.1	3.8	0.4	-0.5	1.4
667	63	47	126	36	0.0	.	3.0	.	-3.0	.
668	63	50	121	59	3.3	1.1	1.8	2.5	1.5	1.4
669	63	51	125	58	1.5	2.1	1.8	2.5	-0.3	0.4
670	63	52	121	20	2.5	.	0.0	.	2.5	.
671	63	54	120	41	2.5	.	0.0	.	2.5	.
672	63	54	125	19	1.3	1.8	4.5	1.4	-3.3	3.2
673	63	56	124	40	4.0	2.1	1.8	2.5	2.3	4.6
674	63	59	124	1	2.8	0.4	1.8	2.5	1.0	2.1
675	64	2	123	23	3.3	1.1	3.8	0.4	-0.5	1.4
676	64	4	122	43	3.3	1.1	1.8	2.5	1.5	1.4
677	64	4	126	44	5.5	.	0.0	.	5.5	.
678	64	7	122	4	2.5	.	0.0	.	2.5	.
679	64	7	126	5	4.0	2.1	1.8	2.5	2.3	4.6
680	64	9	121	25	2.5	.	0.0	.	2.5	.
681	64	10	125	26	4.0	2.1	1.8	2.5	2.3	4.6
682	64	13	124	47	2.5	0.0	1.8	2.5	0.8	2.5
683	64	16	124	8	3.3	1.1	3.8	0.4	-0.5	1.4
684	64	19	123	28	3.3	1.1	1.8	2.5	1.5	1.4
685	64	21	122	49	2.5	.	0.0	.	2.5	.
686	64	21	126	51	5.5	.	0.0	.	5.5	.
687	64	23	122	9	2.5	.	0.0	.	2.5	.
688	64	24	126	12	6.5	.	0.0	.	6.5	.
689	64	26	121	30	2.5	.	0.0	.	2.5	.
690	64	27	125	33	4.0	2.1	1.8	2.5	2.3	4.6
691	64	30	124	53	2.5	0.0	1.8	2.5	0.8	2.5
692	64	33	124	14	2.5	.	0.0	.	2.5	.
693	64	34	127	38	5.5	.	0.0	.	5.5	.
694	64	36	123	34	2.5	.	0.0	.	2.5	.
695	64	38	122	54	2.5	.	0.0	.	2.5	.
696	64	38	126	59	6.5	.	0.0	.	6.5	.
697	64	40	122	15	2.5	.	0.0	.	2.5	.
698	64	41	126	19	5.5	.	0.0	.	5.5	.
699	64	44	125	40	2.5	.	0.0	.	2.5	.
700	64	47	125	0	2.5	.	0.0	.	2.5	
701	64	47	128	26	6.0	.	0.0	.	6.0	.

OBS	LATD	LATM	LOND	LONM	1XCO2	STD	2XCO2	STD	CHANGE	STD
702	64	50	124	20	2.5	.	0.0	.	2.5	.
703	64	51	127	46	4.0	3.5	1.5	2.1	2.5	5.7
704	64	52	123	40	3.3	1.1	1.8	2.5	1.5	1.4
705	64	54	127	6	5.5	.	0.0	.	5.5	.
706	64	55	123	0	3.3	1.1	1.8	2.5	1.5	1.4
707	64	57	122	20	3.3	1.1	2.3	1.8	1.0	0.7
708	64	58	126	27	5.5	.	0.0	.	5.5	.
709	65	0	129	14	6.0	.	0.0	.	6.0	.
710	65	1	125	47	2.5	.	0.0	.	2.5	.
711	65	4	125	7	2.5	.	0.0	.	2.5	.
712	65	4	128	34	6.5	.	0.0	.	6.5	.
713	65	6	124	26	3.3	1.1	1.5	2.1	1.8	1.1
714	65	7	127	54	4.0	2.1	1.5	2.1	2.5	4.2
715	65	9	123	46	3.3	1.1	1.8	2.5	1.5	1.4
716	65	11	127	14	5.5	.	0.0	.	5.5	.
717	65	12	123	6	3.3	1.1	1.8	2.5	1.5	1.4
718	65	14	126	34	2.5	.	0.0	.	2.5	.
719	65	17	125	54	3.3	1.1	1.5	2.1	1.8	1.1
720	65	17	129	23	5.0	1.4	1.5	2.1	3.5	3.5
721	65	20	125	13	3.3	1.1	1.5	2.1	1.8	1.1
722	65	20	128	43	5.3	1.8	1.5	2.1	3.8	3.9
723	65	23	124	33	3.3	1.1	1.5	2.1	1.8	1.1
724	65	24	128	3	3.3	1.1	1.5	2.1	1.8	1.1
725	65	26	123	52	3.3	1.1	1.8	2.5	1.5	1.4
726	65	28	123	11	3.3	1.1	2.3	1.8	1.0	0.7
727	65	28	127	22	3.3	1.1	1.5	2.1	1.8	1.1
728	65	31	126	42	3.3	1.1	1.5	2.1	1.8	1.1
729	65	33	129	32	5.0	1.4	3.5	0.7	1.5	0.7
730	65	34	126	1	3.3	1.1	1.5	2.1	1.8	1.1
731	65	37	125	20	3.3	1.1	1.5	2.1	1.8	1.1
732	65	37	128	52	3.3	1.1	3.5	0.7	-0.3	1.8
733	65	40	124	40	2.5	2.1	1.8	2.5	0.8	0.4
734	65	41	128	11	3.3	1.1	3.5	0.7	-0.3	1.8
735	65	43	123	58	2.5	2.1	1.8	2.5	0.8	0.4
736	65	44	127	31	3.3	1.1	3.5	0.7	-0.3	1.8
737	65	46	130	22	5.0	1.4	4.3	1.8	0.8	0.4
738	65	47	126	50	2.5	2.1	1.5	2.1	1.0	0.0
739	65	50	129	42	3.3	1.1	3.5	0.7	-0.3	1.8
740	65	51	126	9	2.5	2.1	1.5	2.1	1.0	0.0
741	65	53	129	1	3.3	1.1	3.5	0.7	-0.3	1.8
742	65	54	125	28	2.5	2.1	1.8	2.5	0.8	0.4
743	65	57	124	46	2.5	2.1	3.8	0.4	-1.3	2.5
744	65	57	128	20	3.3	1.1	3.5	0.7	-0.3	1.8
745	65	58	131	13	4.0	.	3.0	.	1.0	.
746	66	1	127	39	2.5	2.1	1.5	2.1	1.0	0.0
747	66	2	130	32	2.5	2.1	1.5	2.1	1.0	0.0
748	66	4	126	58	2.5	2.1	1.5	2.1	1.0	0.0
749	66	6	129	51	2.5	2.1	1.5	2.1	1.0	0.0
750	66	7	126	16	2.5	2.1	3.8	0.4	-1.3	2.5
751	66	10	125	35	2.5	2.1	3.8	0.4	-1.3	2.5
752	66	10	129	10	2.5	2.1	1.5	2.1	1.0	0.0
753	66	14	128	29	2.5	2.1	1.5	2.1	1.0	0.0
754	66	14	131	23	2.5	.	6.5	.	-4.0	.
755	66	17	127	47	2.5	2.1	3.8	0.4	-1.3	2.5
756	66	18	130	42	2.5	2.1	4.3	1.8	-1.8	3.9
757	66	21	127	6	2.5	2.1	3.8	0.4	-1.3	2.5
758	66	22	130	1	2.5	2.1	1.5	2.1	1.0	0.0
759	66	26	129	19	2.5	2.1	1.5	2.1	1.0	0.0
760	66	30	128	38	2.5	2.1	3.8	0.4	-1.3	2.5
761	66	30	131	34	2.5	.	6.5	.	-4.0	
762	66	35	130	52	1.0	.	6.5	.	-5.5	.
763	66	39	130	11	2.5	2.1	4.3	1.8	-1.8	3.9
764	66	43	129	29	2.5	2.1	3.8	0.4	-1.3	2.5
765	66	47	131	45	3.3	1.1	4.5	2.8	-1.3	3.9
766	66	51	131	3	3.3	1.1	2.5	0.0	0.8	1.1
767	66	55	130	21	1.0	.	2.5	.	-1.5	.
768	66	59	129	39	2.5	2.1	3.0	0.7	-0.5	1.4
769	67	3	131	56	3.8	1.8	2.5	0.0	1.3	1.8
770	67	7	131	13	3.8	1.8	2.5	0.0	1.3	1.8
771	67	10	133	31	4.0	.	4.0	.	0.0	.
772	67	11	130	31	3.8	1.8	3.3	1.1	0.5	0.7
773	67	15	132	49	4.0	.	4.0	.	0.0	.
774	67	19	132	7	3.8	1.8	2.5	2.1	1.3	0.4
775	67	21	134	25	4.0	.	4.0	.	0.0	.
776	67	23	131	24	3.8	1.8	2.5	0.0	1.3	1.8
777	67	26	133	43	4.0	.	4.0	.	0.0	.
778	67	28	130	42	3.8	1.8	3.3	1.1	0.5	0.7
779	67	31	133	1	5.0	.	4.0	.	1.0	
780	67	32	135	20	5.0	.	4.0	.	1.0	
781	67	35	132	18	3.8	1.8	2.5	2.1	1.3	0.4
782	67	37	134	38	5.0	.	4.0	.	1.0	.
783	67	40	131	35	3.8	1.8	2.5	2.1	1.3	0.4
784	67	42	133	56	3.8	1.8	2.5	2.1	1.3	0.4
785	67	47	133	13	3.8	1.8	2.5	2.1	1.3	0.4
786	67	48	135	34	5.0	.	4.0	.	1.0	.
787	67	51	132	30	3.8	1.8	2.5	2.1	1.3	0.4
788	67	53	134	51	5.0	.	4.0	.	1.0	.
789	67	56	131	47	3.8	1.8	2.5	2.1	1.3	0.4
790	67	58	134	8	3.8	1.8	2.5	2.1	1.3	0.4
791	68	3	133	25	3.8	1.8	2.5	2.1	1.3	0.4
792	68	4	135	47	5.0	.	4.0	.	1.0	.
793	68	7	132	42	3.8	1.8	2.5	2.1	1.3	0.4
794	68	9	135	4	5.0	.	4.0	.	1.0	

Modelling Forest Dynamics In The Mackenzie Basin Under A Changing Climate

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Forest productivity is the result of many different environmental factors, some of which are directly related to climate conditions. The objective of the research reported on here was to relate species composition and productivity on forest land exclusively to climate conditions. However, it must be kept in mind that other factors besides climate affect these forest characteristics as well (Hartley, 1995).

Database Development

In order to develop relationships between forest inventory data and climate conditions, the initial forest inventory information had to be refined and transformed to a level where geographic connections could be made with climate information.

Provincial and territorial stand-level inventories [from British Columbia, Alberta, Saskatchewan, Northwest Territories, and Yukon, covering 178 million hectares (84% of the Mackenzie Basin area)] taken over the past 20 to 30 years (depending on location) were compiled to form the Mackenzie Basin inventory database. Data were obtained from the National Forest Database[1] for all provinces and territories except Alberta, which supplied a portion of its Phase III[2] data (1976 to 1993) for the project[3]. Inventory units varied in size and shape throughout the Mackenzie Basin, and were each geo-referenced with a unique set of latitude and longitude values that could be used to match up with climate data.

Six of the 12 species present were chosen for use in this study, based on their wide distribution and interest for future commercial use: black spruce, white spruce, lodgepole pine, Jack pine, paper birch and trembling aspen. Lodgepole and Jack pine were treated as one species in the analysis due to their ability to interbreed, and common characteristics. They will be referred to as "pine" from this point onwards, and the number of species will be considered to be five.

The multiple stand records found within each of the inventory units were defined using 14 variables (such as: main genus, forest type and age class) from the forest database. Records with incomplete observations were removed, leaving 33.7 million hectares in 6683 inventory units (covering 18% of the Mackenzie Basin area) from Yukon Territory and the provinces of British Columbia and Alberta. It is important to note that all volumes recorded in the inventory database were merchantable. This means that stands of poor quality, non-commercial species or ages may not have been recorded, which then generates a biased representation of the measured forest land.

Individual stands within inventory units were aggregated into stand-types using age, main genus and forest type (**Figures 1a & 1b and Table 1**). The over all inventory unit values for species volume per hectare and for species proportion were then generated as means weighted by

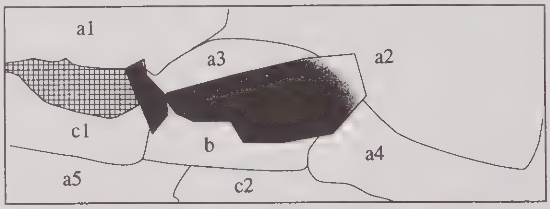


Figure 1a. Multiple stand records within an inventory unit are aggregated into stand-types (for calculations, see Table 1).

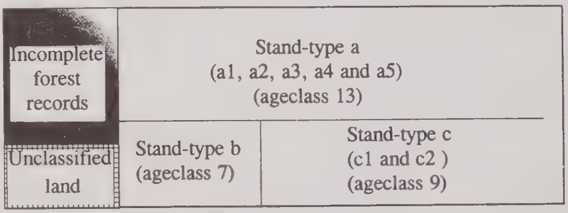


Figure 1b. Overall inventory unit forest values generated from stand-type weighted means by area (for calculations, see Table 2).

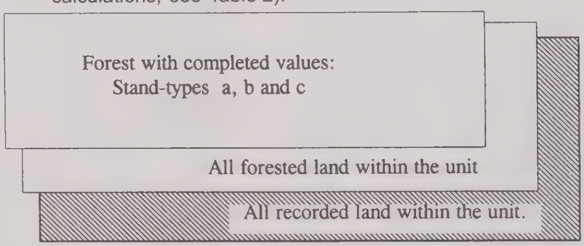


Figure 1c. The aggregation and transformation of a hypothetical inventory unit's forest values.

stand area (**Figures 1b & 1c and Table 2**). These aggregated forest inventory unit values were later transferred from SAS datasets to the GRASS GIS to create raster map-layers for use in the Mackenzie Basin Forest Productivity model (MBFP model).

Forest land productivity for the five species was based on ageclass and standing volume, with mean decadal volume increment (MDI, in $m^3/ha/10$ years) as the measure. Each species was assigned 6 stages of growth development, with the age boundaries between the age groups selected based on a knowledge of the silvics of each species[4] (**Figure 2**). The MDI for each the first three age groups for each species, was calculated within each inventory unit (**Table 2**) and served as a measure of average periodic growth. At the inventory unit level, relationships could then be developed between these forest values and climate conditions.

Table 1. The aggregation of a hypothetical inventory unit's multiple stand records to stand-type records.

Stand-type Multiple Records for unit BC094C14E	Size (ha)	Black Spruce (m^3/ha)	White Spruce (m^3/ha)	Pine (m^3/ha)	Trembling Aspen (m^3/ha)	Paper Birch (m^3/ha)
a1	79	0.00	21.60	79.70	0.00	0.00
a2	182	0.00	25.45	62.40	0.00	0.00
a3	142	0.00	26.55	92.20	0.00	0.00
a4	224	0.00	38.40	98.71	0.00	0.00
a5	64	0.00	34.80	88.60	0.00	0.00
b	256	0.00	19.90	0.00	24.10	0.00
c1	215	0.00	0.00	6.76	4.35	0.00
c2	167	0.00	0.00	5.25	3.55	0.00
Sum of Weighted Volume (m^3)	a	0 00	20937.20	58527 70	0 00	0 00
	b		5094.40	0.00	6169 60	0 00
	c		0.00	2330 20	1527 75	0 00
Mean Weighted Volume (m^3/ha)	a.	0 00	30 30	84 70	0 00	0 00
	b		19 90	0 00	24 10	0 00
	c		0 00	6 10	4 00	0 00
Proportion by Volume	a	0 00	0 264	0 737	0 00	0 00
	b:		0.452	0.00	0.548	0.00
	c:		0.00	0.604	0.396	0.00

Table 2. The transformation of a hypothetical inventory unit's stand-type records to a set of overall inventory unit values.

Stand-type for unit BC094C14E	Age Class	Size (ha)	Black Spruce		White Spruce		Pine		Trembling Aspen		Paper Birch	
			P	m^3/ha	P	m^3/ha	P	m^3/ha	P	m^3/ha	P	m^3/ha
a	13	691	0.000	0.00	0.264	30.30	0.737	84.70	0.00	0.00	0.000	0.00
b	7	256	0.000	0.00	0.452	19.90	0.000	0.00	0.548	24.10	0.000	0.00
c	9	382	0.000	0.00	0.000	0.00	0.604	6.10	0.396	4.00	0.000	0.00
Sum of Weighted Unit Values	14213		0 000	0 00	297 9	26031	739 7	60857	291 5	7697	0 000	0 00
Mean Weighted Unit Value (m^3/ha)	10 70		0.000	0.00	0 224	19 59	0 557	45 79	0.219	5.79	0.000	0.00
Mean Decadal Increment ($m^3/ha/10$ years)				0 00		1.83		4.28		0.54		0.00

"P" refers to the Proportion within the cell.

Climate To Species Relationships

The projection of forest inventory characteristics through climate change requires that relationships be developed between these characteristics and climate variables. The range of productivity and species presence within the inventoried area of the Mackenzie Basin was used as an indicator of species response to environmental conditions. Multiple linear regression (using a forward stepwise procedure) was employed to develop equations between each species proportion within an inventory unit and climate conditions, and between each species productivity for the first three age groups and climate conditions.

Climate conditions were represented by the temperature and precipitation baseline values generated for the Mackenzie Basin area from 1951-80 weather station records. Seventeen variables were selected as potential independent variables for the regression equations. These were used in different combinations for each of the final regression equations. Some of the regression relationships had poor predictive powers. This was especially evident for the deciduous species, and all species in Age Group I. However, all but three of the equations were highly significant (p values of less then 0.0001). These regression relationships were used in the MBFP model in the growth and establishment modules.

The Mackenzie Basin Forest Productivity Model

The MBFP model was built to analyze the effects of transient climate change scenarios on forest land productivity. The transient GISS GCM was selected for predicting changes to mean monthly temperature and precipitation in ten year timesteps up to the year 2050. The simplistic forest dynamics model was supported by the Geographical Resources Analysis Support System (GRASS). This UNIX-based Geographic Information System (GIS) supports shell script modelling, and performs arithmetic calculations on raster map-layers.[5] It was able to run on a personal computer using the Linux operating system (with GRASS to Linux bina-

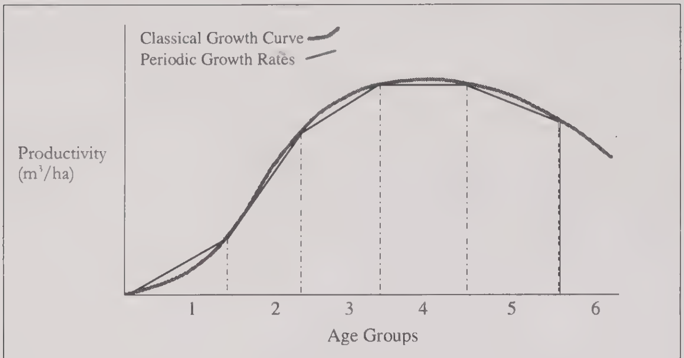
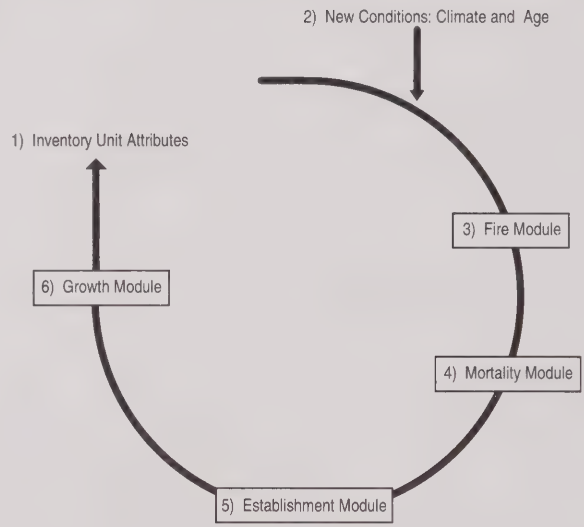


Figure 2: Development Stages of Tree Growth. The first three age-groups consist of positive growth, with age-group I comprising early, accelerating growth, age-group II comprising the higher growth rates that occur as maturity is approached, and age-group III comprising the lower growth rate of older stands. The latter three groups were assumed to have no growth or negative growth, with age-group IV having no net increase, age-group V comprising a 10% decrease in the standing volume over a ten year period, and age group VI resulting in the loss of all that species volume (through mortality) over a ten year period.

ries).[6]

The approach used for the MBFP model employed the simplistic connection of the major forest dynamic processes presented in **Figure 3**. The processes of fire disturbance, species stress-induced mortality, species establishment, and growth were arranged to run in ten-year time steps from 1980 to 2050. Within each ten-year time step, the species age groups (**Figure 2**) used in assigning volume increment or reduction, were reassessed with the new age value for each unit. The MBFP model completes a single run after all seven time steps have been executed. Standing volume for each species, unit age, and proportional occupancy by species can change for each inventory unit over the time steps of a single model run.

The sub-shell modules created within the MBFP model super-shell represented: fire events, species death due to poor climate conditions, proportional establishment of the five species after unit disturbance, and individual species growth. These modules were configured to be easily adjusted and updated for future changes to the MBFP model. The relationships built for the MBFP model between baseline 1951-1980 climate conditions and forest inventory attributes were held constant for all GCM scenario runs.



1) Weighted mean age; species proportional occupancy; species standing volume.
2) Climate and Seasonal FWI for the current time step; weighted mean age and species age groups for the current timestep (i.e. plus ten years).
3) Possible unit disturbance based on seasonal FWI distribution and seasonal FWI frequency.
4) Species age and predicted growth for the climate conditions determine mortality. Unit disturbance occurs once cell occupancy reaches 0.5 or less.
5) Unit age of five years, and species establishment proportions (as determined by climate conditions) assigned for units disturbed by fire or mortality. Merchantable volume removed from the unit, and all species assigned Age Group I.
6) Species growth based on species age group, climate conditions, proportion occupancy and unit area of forested land. Volume generated summed with unit's previous timestep value.

Figure 3. The Mackenzie Basin forest productivity model cycle.

Major Forest Dynamic Processes Represented By Modules

Fire Module

The first form of inventory unit disturbance is generated within the fire module. The rules of fire disturbance were established using: (1) the number of units burned within the Mackenzie Basin modelled area in a 10-year time period, based on a disturbance frequency related to the weighted mean age of the inventory units; (2) classifica-

tion of seasonal fire weather index (FWI), which indicates fire hazard based on seasonal temperature and precipitation; and (3) a ratio between the area burned and the seasonal FWI class.

Unit disturbance was assumed to involve the loss of the entire standing volume of a unit. The weighted mean age of inventory units for the modelled area of the Mackenzie Basin was 91.46 years. This suggested a 10.9% chance of unit disturbance every ten years. As no other disturbances, such as harvesting or insect attack, were included in the MBFP model, the entire unit disturbance frequency was assigned to fire occurrence. No allowance for spread was made in the fire module (as rules were not determined for spread across the variable inventory unit sizes and forested land areas within units); thus, fire disturbance was allocated to units randomly, without accounting for neighbors.

Seasonal FWI values were classified into three categories based on the mean of June, July and August FWI values (**Figure 6**). Each category represented a hazard level of a randomly distributed fire ignition event causing unit disturbance, with the highest FWI category holding the greatest probability for unit disturbance. For each seasonal FWI category, the number of units to be burned was related to a ratio of area burned-to-seasonal FWI categories. This ratio was based on data from the Fort Smith and Yellowknife climate stations, including their surrounding fire history.[7] Although this area is not within the MBFP models' geographic region, this information was the best available.

Mortality Module

The second form of inventory unit disturbance was generated within the mortality module, as defined by species age and productivity under the current climate conditions. Each species was assigned a range of productivity at Age Group III, divided into three categories of poor, medium and good.[8] Age Group III was chosen for classification purposes because established mature stands likely had better inventory data to be referenced for determining growth response then younger or older stands. Any species with a unit age that places it in Age Group III or greater, and that also had a poor productivity (as predicted by climate parameters), was defined as dead. The species occupancy for that unit was then transported to a raster map-layer representing the unit's proportional occupancy by mortality. When 50% or more of the unit occupancy consisted of mortality, it was considered disturbed, the standing volume of all the species removed, and the unit opened for establishment.

Establishment Module

Proportional establishment by the various species in a unit was calculated using the relationships between proportional occupancy and climate variables developed earlier. After unit disturbance by fire or mortality, the establishment module reset the unit with a new species composition (which is dependant only on the current climate values) and assigned a zero value to the volume of each species within the unit, as well as to the proportion of mortality. Unit age was then set to the time steps' midpoint of five years, and each species assigned to the first age group for determining growth rates.

Growth Module

The growth module is the final step in the MBFP model cycle, as all units now hold the current (post disturbance) age, species proportions, and volumes. The growth rates for each species in each age group were calculated from the climate to species productivity regression relationships to determine productivity values. These values were then adjusted for application to units with variable species proportions, and forested areas. The volumes produced (positive or negative) by each species within the time step were then added to the standing volume for that species within the unit. If a species had its volume reduced in the time step to be less than or equal to zero, then the proportion of the unit occupied by that species was assigned to the raster map layer representing proportion of mortality.

After a cycle through these four modules, each unit had: (1) a chance of being burnt; (2) each species tested for climatic stress (poor productivity, and Age Group III or greater) and possibly killed; (3) the chance of being regenerated (in the case of fire or cumulative mortality leading to unit death); and (4) growth in the volume of each species present. The new unit values were then cycled through the modules again, using the climate conditions predicted for the next decade. After all the cycles through the climate scenario were completed, changes in the inventory unit attributes over time were assessed.

Results

The MBFP model was run through scenarios both with and without climate change. Each scenario's results were assessed on the averages of five runs. The results shown here are from the low fire frequency scenario (meaning the frequency of fire was reduced by 10% from that of the initial 10.9% per 10 years). The area affected by the

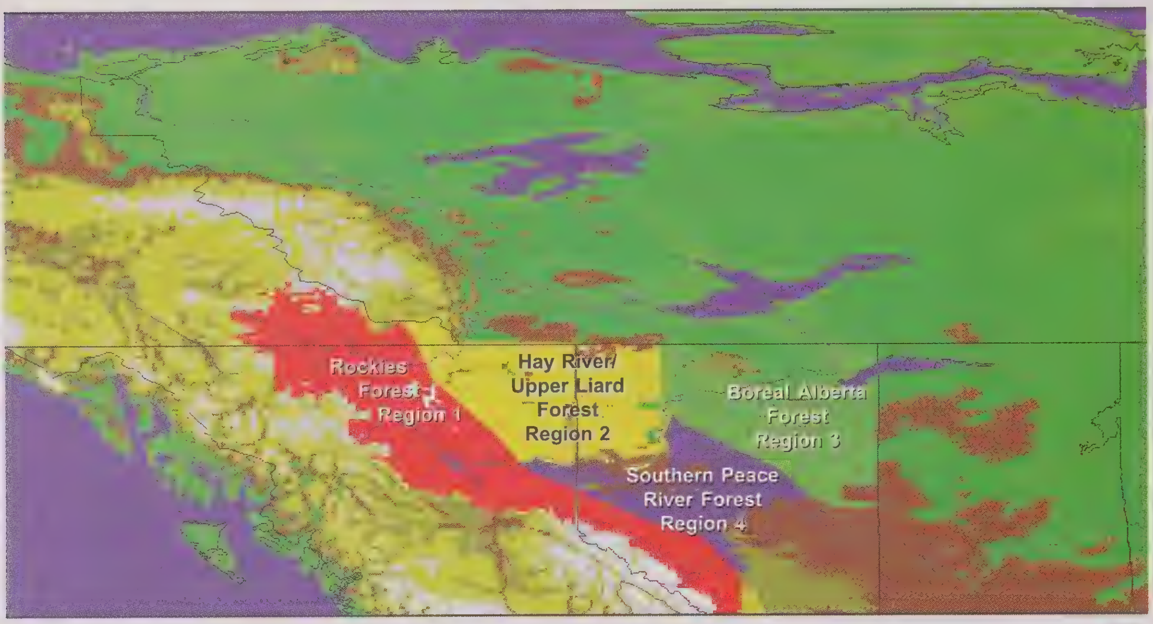


Figure 4. Forest Regions.

model was stratified by four geographic regions (**Figure 4**). These were developed using topography and Rowe's (1972) forest regions. The initial inventory values differ between regions, with the proportion of each species shown in the stack graphs (**Figure 5**).

The number of unit disturbances from fire increase with climate change for all the regions (**Figures 6 and 7**). Together with the effects of the mortality module, this decreases the mean inventory unit age over time as the older inventory units are replaced through disturbance (**Figure 8**). This causes a change in forest productivity over the regions, as the less productive older units are re-established as highly productive younger units. Productivity is defined as the volume per hectare produced over time on a finite landbase (**Figure 9**).

With unit disturbance and re-establishment the species composition changes over time. The regions show an overall increase in the proportion of coniferous species (**Figure 10**). As species volume within units is increased by growth and removed by disturbance at different rates both with and without climate change, a net change in standing volume occurs for each region (**Figure 11**). The increased frequency of unit disturbance under climate change is prohibitive to the build up of standing volume, and thus volume drops as climate re-

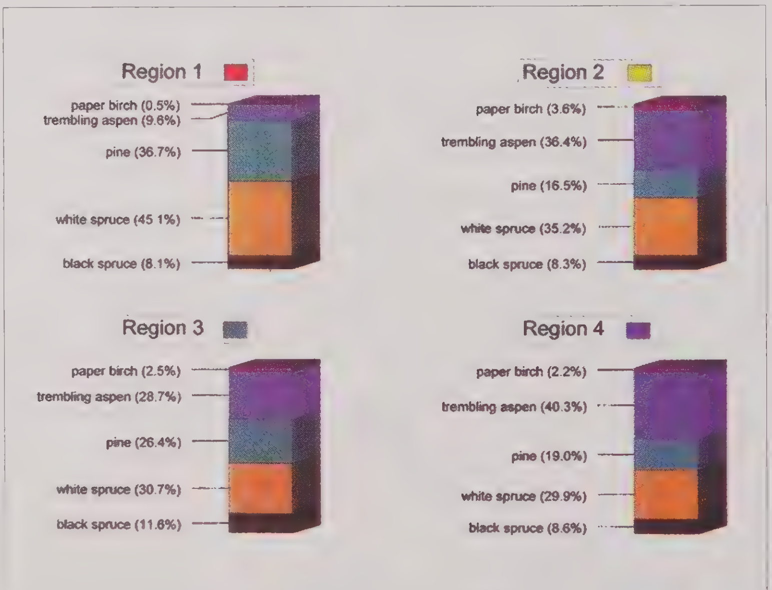


Figure 5. 1980 Species Proportions by Region.

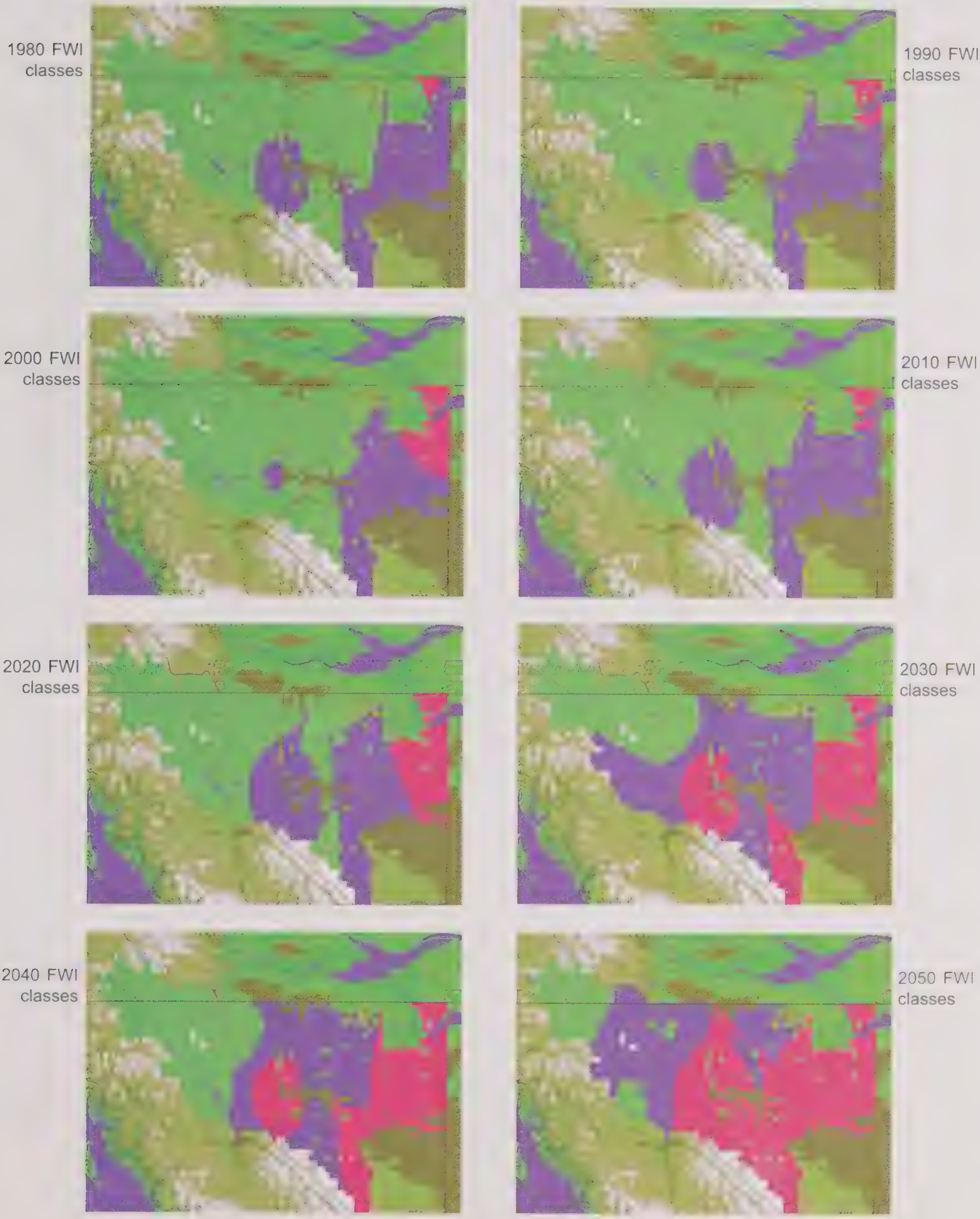


Figure 6. FWI classes through climate change for use in the MBFP model.

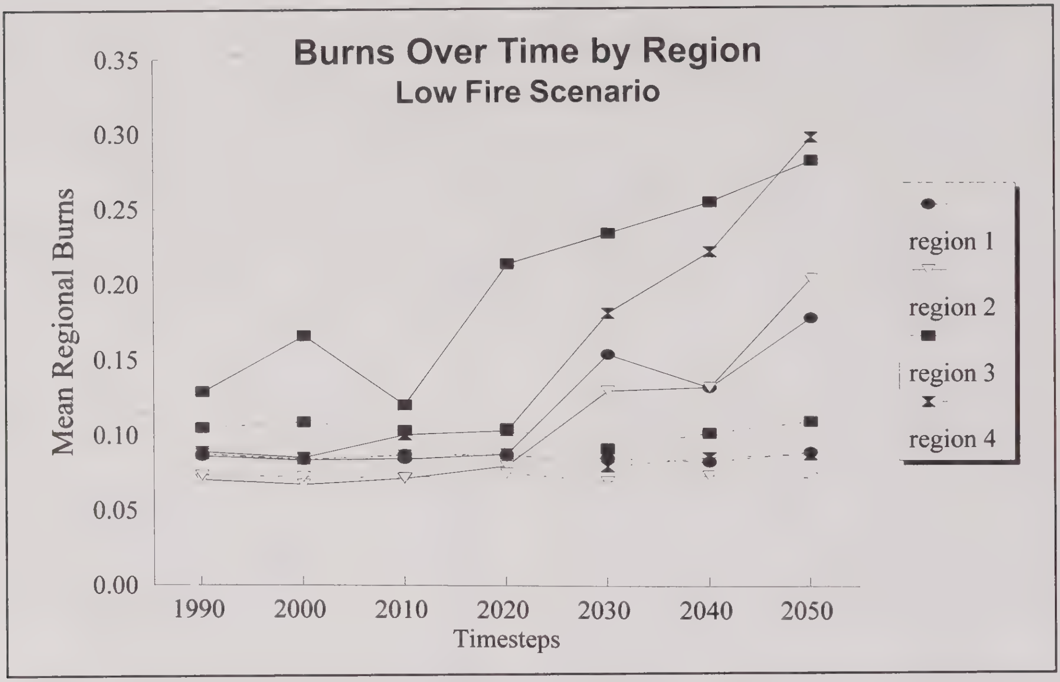


Figure 7. Fire disturbance of inventory units (dashed line = without climate change).

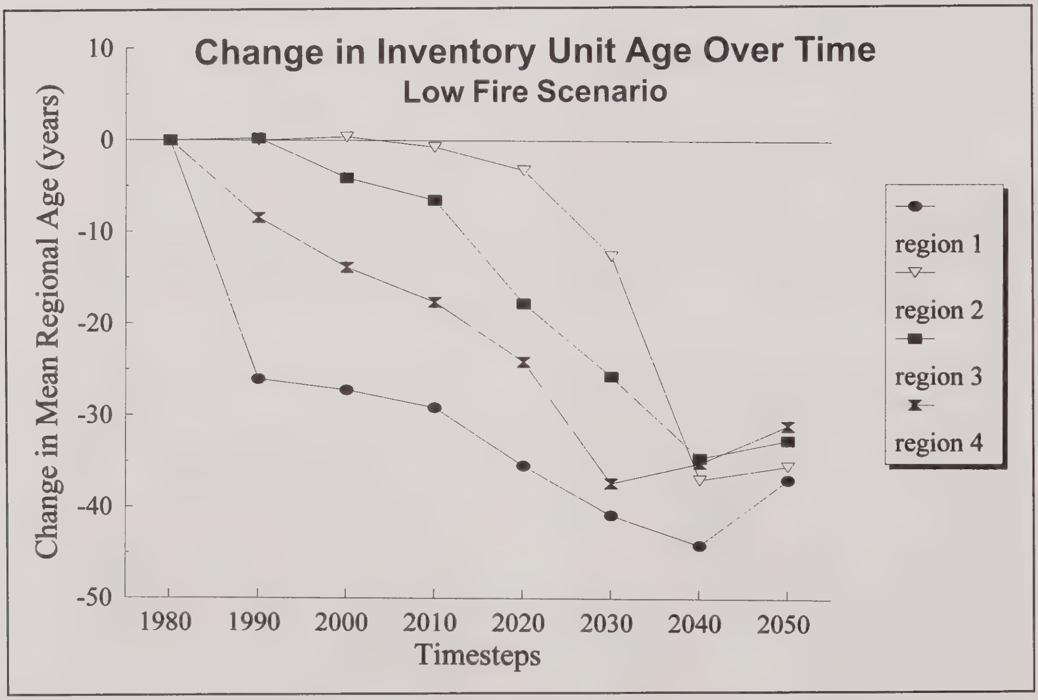


Figure 8. Inventory unit age over time.

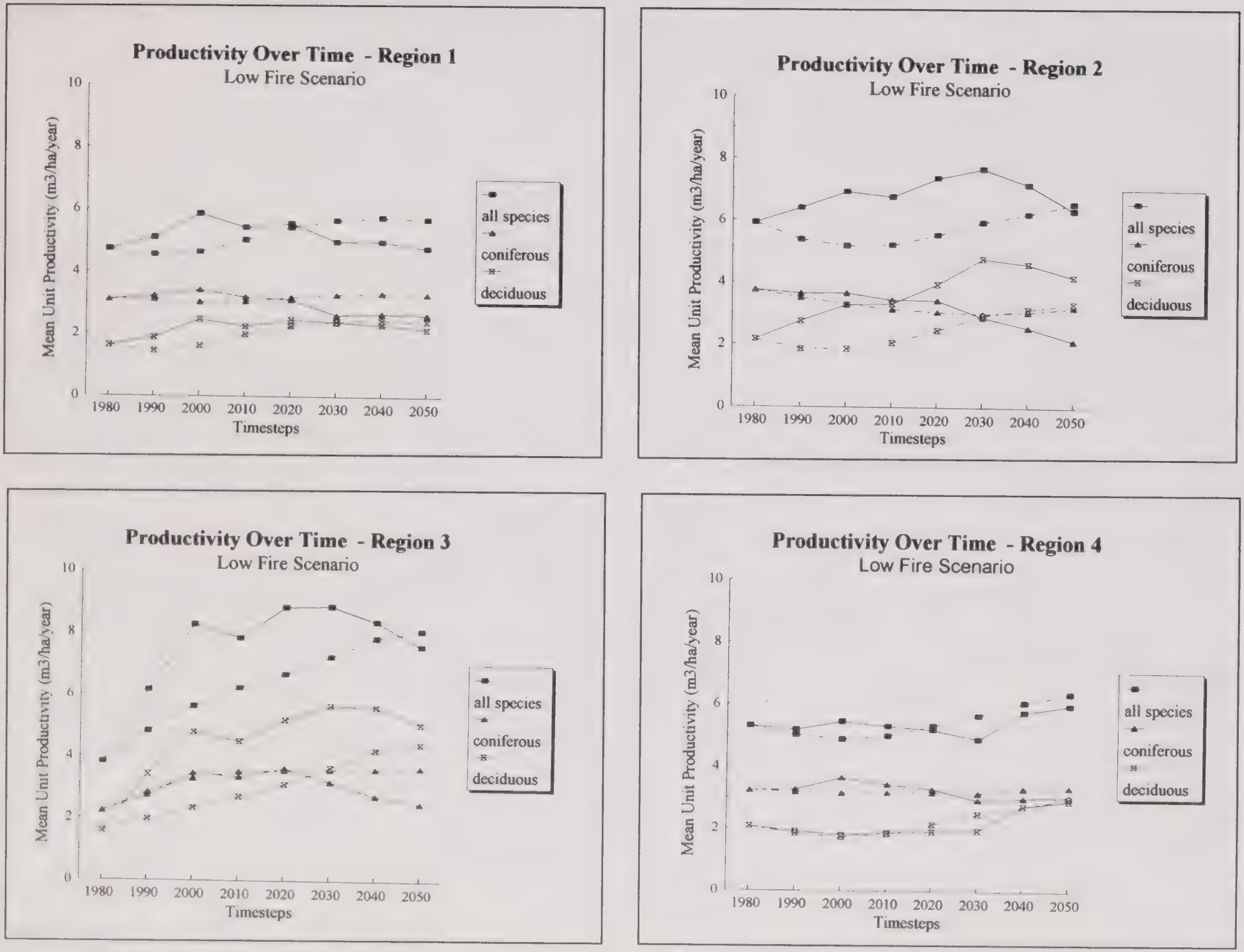


Figure 9. Forest productivity over the regions (dashed line = without climate change).

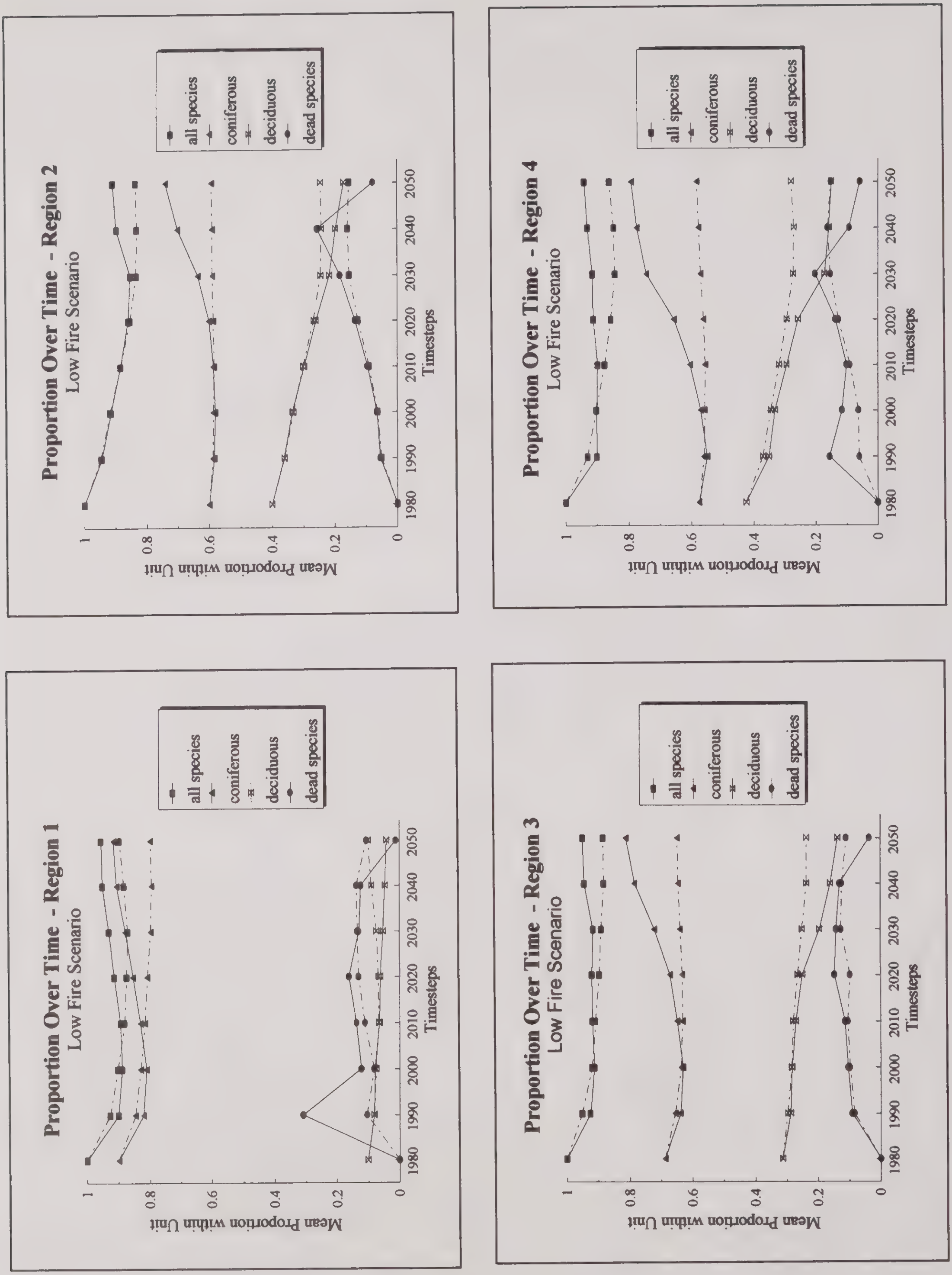


Figure 10. Species proportion over time (dashed line = without climate change).

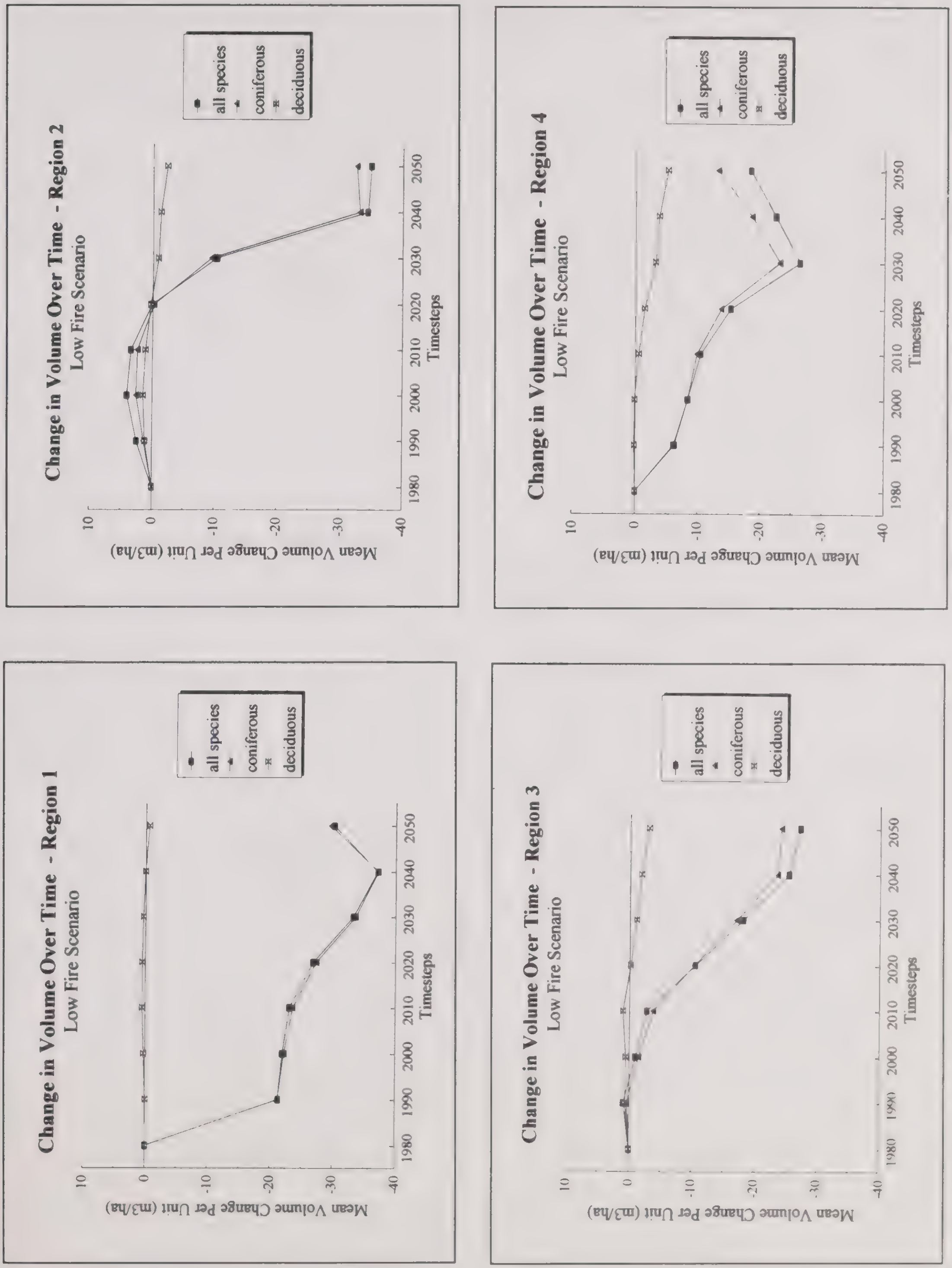


Figure 11. Change in standing volume.

lated disturbances increase.

Conclusions

Species composition and productivity on forest land was projected through the transient GISS climate change scenario based on the multiple linear regression equations developed. The preliminary results indicate an increase in fire disturbance which leads to an overall increase in forest productivity, and decrease in standing volume and age.

Further sensitivity tests and analysis of the MBFP model results need to be done to help understand the limitations and predictions of the simplistic forest dynamics model. The area covered by the MBFP model is limited to the area of complete forest inventory data for the Mackenzie Basin. An increase in the study area would allow for a greater range of climate conditions to be considered, increasing the models' robustness.

Notes

1. Maintained by the Canadian Forest Service.
2. Alberta Environment Protection, Forest Inventory.
3. These data were organized and completed by Ross Benton, Forest Climatologist, Pacific Forestry Centre, Canadian Forest Service, Victoria.
4. It is expected that the environmental conditions at the local scale will affect growth patterns, causing the time spent at each stage to vary.
5. Raster map-layers contain geographic information assigned to the centroid of regularly distributed cells over the map surface. The individual cell is called a pixel. Pixel values can be processed using arithmetic calculations in GRASS, with the current active resolution using data values from the closest pixel centroid. More information on GIS data storage can be found in any GIS textbook.
6. Both Linux and GRASS are available as public domain software. Linux kernel version 1.1, Slackware 2.0, Infomagic, Rocky Hill, NJ. GRASS 4.1, United States Army Corps of Engineers, Construction Engineering Research Laboratories, Champaign, Illinois.
7. The analysis of FWI to area burned for Fort Smith and Yellowknife was performed by Lisa Kadonaga, Graduate student, University of Victoria, Victoria. See report by Kadonaga elsewhere in this volume.
8. These categories of species productivity were defined by the junior author based on growth projections for pure stands of each species.

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Forecasting Future Fire Susceptibility in the Mackenzie Basin

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Abstract

Fire is a major source of disturbance in the boreal forest. Since weather conditions are closely linked to fire occurrence, climate change could potentially affect the fire regime in northern Canada. Monthly temperature, precipitation, and Fire Weather Index (FWI) data have been used to develop equations describing present-day relationships between climate and fire risk, for 15 stations located in or near the Mackenzie Basin. These were combined with climate change projections obtained from the Canadian Climate Centre (CCC) and Goddard Institute (GISS) 2×CO_2 scenarios, to estimate future susceptibility to fires. Although increases in summer precipitation are predicted for much of the region, it may not be enough to offset warmer temperatures. Both models forecast higher fire danger for several stations. The CCC scenario projects most of the changes occurring in midsummer, while the GISS scenario implies an earlier start to the fire season. Accuracy is limited by data availability, the sporadic nature of severe fire years, and uncertainty over the magnitude and location of future climate changes.

Introduction

Weather conditions and wildfire are connected in many different ways. Sometimes these relationships are direct: summer drought is known to increase fuel flammability, and lightning storms account for many fire starts. In other cases the linkages may be more subtle, such as fuel buildup over a number of years due to favourable growing conditions. Various authors have explored the possible relationships between climate oscillations like El Niño, and severe fire seasons (Swetnam and Betancourt 1990, Johnson and Wowchuk 1993). Other researchers have considered the possible impacts of climate change on fire regimes, past (Terasmae and Weeks 1979, Clark 1990) and future (Beer et al. 1988, Balling et al. 1992, Torn and Fried 1992).

Fire is of special interest to ecologists because it plays a key role in forest disturbance, particularly in boreal environments (Wright and Heinselman 1973, Wein and MacLean 1983). The frequency and severity of burns affects the size, age, and composition of the stands, as well as the lichen and shrubs that make up the undergrowth. Where the forest meets grassland or tundra, treeline position is not only influenced by soils and climate, but by fire occurrence as well (Sirois and Payette 1991).

This study attempts to forecast future fire risk in the Mackenzie Basin, if climate warming occurs as a result of increasing concentrations of greenhouse gases in the atmosphere. Recorded temperature, precipitation, and Fire Weather Index (FWI) values have been used to develop equations for present-day relationships between climate and forest fire. In combination with data from global warming projections such as the Canadian Climate Centre general circulation model, these equations can be used to estimate future fire danger.

The Fire Weather Index is one of six variables developed by the Canadian Forestry Service through the 1970s and 1980s as part of the Canadian Forest Fire Danger Rating System (Canadian Forestry Service 1987). It is used as a daily measure of fire danger at a particular location, and is popular among resource managers and fire professionals as an indicator of how difficult it would be to extinguish a blaze, should one ignite (Ralph Kermer, pers. comm. 1992).

Instead of number of fires or area burned, this study focuses on fire danger, because of the difficulty in obtaining monthly and sub-regional fire data. In addition, FWI is calculated from meteorological variables (temperature, relative humidity, precipitation, and wind speed) measured at a specific point, while fire data are scale-dependent. All other things being equal, the probability of a fire occurring somewhere increases with the size of the study area. This makes it difficult to extrapolate fire occurrence onto larger or smaller regions.

It should be noted that area burned may not be synonymous with the number of fire starts. It is possible to have many small fires which are extinguished or go out of their own accord, and do not consume much forest. Lakes, bogs, rock outcrops, and earlier burns can serve as natural firebreaks which prevent fires from spreading, so the particular characteristics of a landscape can also be important.

Previous work in the NWT has demonstrated positive relationships between median summer FWI values and burned area (Kadonaga 1992). For fires larger than 0.25 square kilometres, the annual area burned during the peri-

od 1967-1989 was estimated for sample quadrats located near Fort Smith and Yellowknife. Quadrat boundaries were equivalent to 1 : 250 000 topographic map sheets.

For the area east and northwest of Yellowknife (map sheets 85i, k, m, n, o, and 86c, d, f), the best-fit linear regression equation was as follows:

$$AAB = 87.233 * (FWIsm) - 518.305 \tag{1}$$

where AAB is annual area burned in square kilometres, and FWIsm is the median FWI value for the summer season (June 1 through August 31).

The equation for the 7 quadrats near Fort Smith (map sheets 75a, b, c, e, f, k, l) was also calculated:

$$AAB = 138.496 * (FWIsm) - 1052.629 \tag{2}$$

In both cases, the direction of the slope demonstrates that the relationship between FWI and area burned is positive. The r-values, f-ratios, and p-values were 0.454, 5.45, and 0.03 respectively for the Yellowknife equation, and 0.596, 11.58, and 0.003 for Fort Smith. (An equation was also developed for Hay River, and although the slope was also positive, it was not statistically significant.)

Methods:

Response surfaces with two or more independent variables have been used by other authors to project future climate-related changes in the environment (Overpeck et al. 1991). In this part of the project, monthly regression equations were developed for 15 stations located in or near the Mackenzie Basin (**Appendix I**). The Atmospheric Environment Service (AES) stations provided the spatial co-ordinates as well as the monthly temperature and precipitation data. Daily FWI records from the nearest site were obtained from separate sources. Stations with fewer than 12 years of data were omitted; many stations which began monitoring in the 1980s could not be used because the period of record was too short. According to Ramsey and Higgins (1991), June, July, and to a lesser extent August, are the main part of the fire season in the northern boreal forest. For this study, the shoulder months, May and September, were also included.

The climate variables used were mean monthly temperature and total monthly precipitation. Although mean temperature does not convey as much information as maximum and minimum values, or extremes, it is available from weather stations and climate models. The fire danger variable is median monthly FWI. Averages could be misleading, because daily FWI values can range from less than one to more than 30. Medians were only taken if there were more than 18 days of data. Regressions were worked out for both log-transformed and unaltered independent variables (**Appendix I**).

Station co-ordinates were used to extract results from the Canadian Climate Centre (CCC) and Goddard Institute (GISS) 2xCO2 climate warming scenarios. These forecasts were input into the monthly regression equations, to estimate future median FWI. The results from the log-transformed equations are presented in **Appendix II**. Equations with p-values in excess of 0.05 are excluded from the tables.

The climate scenarios consist of the CCC model (1951-80 baseline normals and 2xCO2 forecast) and GISS transient model (ten-year increments for 1980 through 2050). For ease of interpretation, the projected FWI medians are classified into fire danger rankings, originally developed by the Canadian Forestry Service (Alexander 1982) and subsequently modified by the Territorial Fire Centre (Rick Lanoville, pers. comm. 1991). For this study, FWI medians between 0 and 5.9 were designated as "low" hazard, while values from 6.0 to 12.9 were "moderate", and so on through "high" (13.0 to 24.9) and "extreme" (25.0 and up). The Territorial Fire Centre scale is in fact more conservative than the original rankings, since the low-moderate boundary is set a full unit higher, and the "very high" (19.0 to 24.9) category has been merged into the "high" category.

The end points of the GISS and CCC models, converted into danger ratings, are presented in **Table 1**. These categories represent monthly medians — if a value is "M", half of the days of the month will have fire danger "moderate" or higher. The G1980 column represents the estimated (1980) baseline for the GISS scenario, and G2050 is the forecast, given a doubling of greenhouse gases. CCCb is the baseline for the CCC scenario, and C2050 is the forecast. There are two different baselines because the models have slightly different starting conditions.

Results:

Table 1 compares baseline fire danger ratings with the forecasts from the model end points. The CCC baseline is calculated from 1951-1980 climatological normals. For this model, most of the stations which change their median FWI categories experience higher fire danger. The only exception is Watson Lake, in July, which drops from "M" (moderate) to "L" (low).

May: Norman Wells, Hay River, Dease Lake (L to M); Ft. Smith, Ft. St. John (M to H)

Jun: Dease Lake (L to M); Norman Wells, Ft. Simpson, Ft. Resolution, Hay River, Ft. St. John, Chetwynd, Mackenzie (M to H)

Jul: Ft. Nelson (L to M); Ft. Smith, Mackenzie (M to H); Watson Lake (M to L)

Aug: Ft. Nelson (L to M); Ft. St. John, Mackenzie (M to H)

Sept: no changes

When the GISS 1980 and 2050 scenarios are compared, higher fire danger categories are forecast for the following stations:

May: Norman Wells, Yellowknife, Ft. Simpson, Hay River, Watson Lake, Dease Lake (L to M); Ft. Smith, Ft. St. John (M to H)

Jun: Dease Lake (L to M); Ft. Smith (M to H)

Jul: Mackenzie (M to H); Watson Lake (M to L)

Aug: Ft. Nelson (L to M), Ft. St. John (M to H)

Sept: Ft. St. John (L to M)

Just as in the CCC 2xCO2 scenario, Watson Lake goes from moderate to low in July.

Discussion:

Both the GISS and CCC 2xCO2 scenarios forecast increases in fire danger for several stations in the study area. However, there are some differences between the models. The number of stations per month that jump to higher categories are as follows:

Month	GISS	CCC
May	8	5
Jun	2	8
Jul	1	3
Aug	2	3
Sept	1	0

The CCC model has the greatest number of changes occurring in June, which is already the peak of the fire season. By comparison, the GISS model places the most emphasis on increasing fire danger in May, which would tend to lengthen the season.

If the numerical values for the projections are used, the average changes for each month, calculated from **Appendix II**, look like this:

Month	GISS	CCC
May	+3.3	+3.0
Jun	+2.4	+4.3
Jul	+1.1	+1.4
Aug	+2.8	+2.3
Sept	+0.9	+0.5

A monthly median in the high "H" category implies that an FWI value in excess of 12.9 occurs on at least nine days (since each month of data has a minimum of 18 days). The CCC baseline, estimated from 1951-80 climate nor-

Table 1 Changes in endpoints for GISS and CCC scenarios

Station names	G1980	G2050	GISS change	5180n	CCC2x	CCC change
MAY						
Norman Wells	L	M	higher	L	M	higher
Yellowknife	L	M	higher	M	M	
Fort Simpson	L	M	higher	M	M	-
Hay River	L	M	higher	L	M	higher
Watson Lake	L	M	higher	M	M	-
Fort Smith	M	H	higher	M	H	higher
Dease Lake	L	M	higher	L	M	higher
Fort St. John	M	H	higher	M	H	higher
Whitehorse, Fort Nelson, Germansen Landing, Mackenzie -- all "M", no change						
JUNE						
Norman Wells	M	M	-	M	H	higher
Fort Simpson	M	M	-	M	H	higher
Fort Resolution	M	M	-	M	H	higher
Hay River	M	M	-	M	H	higher
Fort Smith	M	H	higher	H	H	-
Dease Lake	L	M	higher	L	M	higher
Fort St. John	M	M	-	M	H	higher
Chetwynd	M	M	-	M	H	higher
Mackenzie	M	M	-	M	H	higher
Inuvik, Watson Lake, Fort Nelson, Germansen Landing -- all "M", no change Yellowknife -- all "H", no change						
JULY						
Watson Lake	M	L	lower	M	L	lower
Fort Smith	H	H	-	M	H	higher
Fort Nelson	L	L	-	L	M	higher
Mackenzie	M	H	higher	M	H	higher
Dease Lake -- all "L", no change Inuvik, Norman Wells, Fort Simpson, Fort Resolution, Hay River, Whitehorse, Germansen Landing, Chetwynd, Fort St. John -- all "M", no change Yellowknife -- all "H", no change						
AUGUST						
Fort Nelson	L	M	higher	L	M	higher
Fort St. John	M	H	higher	M	H	higher
Mackenzie	H	H	-	M	H	higher
Inuvik, Norman Wells -- all "L", no change Yellowknife, Fort Simpson, Hay River, Fort Smith, Germansen Landing, Chetwynd -- all "M", no change						
SEPTEMBER						
Fort St. John	L	M	higher	L	L	-
Inuvik, Norman Wells, Yellowknife, Fort Simpson, Hay River, Fort Smith, Fort Nelson, Germansen Landing, Chetwynd -- all "L", no change						

mals, has two stations in the "H" category for one or more months during the May-September season: Ft. Smith and Yellowknife. The CCC 2xCO2 scenario adds Ft. St. John, Norman Wells, Ft. Simpson, Ft. Resolution, Hay River, Chetwynd, and Mackenzie to the "H" category (**Table 1**). The GISS model gives a different result. GISS 1980 has Yellowknife, Ft. Smith, and Mackenzie in the "H" category, while GISS 2050 only adds Ft. St. John.

The CCC and GISS models both forecast increases in summer precipitation for much of the Mackenzie basin, but these scenarios suggest that this may not be enough to offset increases in temperature. Some areas may experience significantly higher FWI for at least one month of the fire season, while only one of the stations in this study, Watson Lake, could end up with a lower fire danger rating.

Table 2 also shows the differences between the two baselines, GISS 1980 and the 1951-80 normal estimates (CCC baseline, or CCCb). In May, Yellowknife, Ft. Simpson, and Watson Lake are in the low category according to the GISS 1980 scenario, while the CCC baseline ranks them as moderate. In June, Fort Smith is moderate for GISS 1980, but high for the CCC baseline.

The pattern is opposite for July, where Fort Smith is ranked in the high category for GISS 1980, but only moderate for the CCC baseline. In August, Mackenzie is also ranked "H" for GISS 1980, and "M" for CCCb. It appears that GISS 1980 gives lower estimates in the early part of the fire season, then trades places with CCCb in July and August. Aside from that, the fire danger categories of the two baseline scenarios are generally in agreement.

Only six of the stations have actual daily FWI data covering the period from 1951 to 1980. **Table 2** compares the fire danger categories for the real monthly median FWI, averaged over that time period, to the GISS 1980 and CCC baselines. Within the categories, the estimated monthly median FWI values are fairly close to the real observations. Admittedly the sample size is limited, and some of the years are missing. Compared to the actual monthly medians, GISS 1980 underestimates the May FWI ranking for Yellowknife ("L" instead of "M"), and the June ranking for Ft. Smith ("M" instead of "H"). Likewise, the CCC baseline gives the July ranking for Ft. Smith as "M" instead of "H". Consistent underestimation of the GISS baseline, compared to the CCC model, may account for some of the differences between the two scenarios for the month of May, as shown in **Table 1**.

Table 2 Comparison of real and estimated baseline FWI

Month	HAYR	FTSM	FTRS	YKNF	NORW	INUV
Monthly median FWI, 1951-80 real measurements						
May	4.73	12.08	6.17	6.41	5.43	1.22
June	7.63	14.89	10.67	15.89	12.30	7.03
July	8.03	14.32	9.12	15.99	8.07	9.21
Aug	6.58	10.32	8.69	11.24	4.16	4.29
Sept	3.61	3.86	-	4.07	2.76	1.90
Monthly median FWI, 1951-80 real measurements, NWT categories						
May	L	M	M	M	L	L
June	M	H	M	H	M	M
July	M	H	M	H	M	M
Aug	M	M	M	M	L	L
Sept	L	L	-	L	L	L
Estimated median FWI, from 1951-80 climate normals and equations						
May	L	M	-	M	L	-
June	M	H	M	H	M	M
July	M	M	M	H	M	M
Aug	M	M	-	M	L	L
Sept	L	L	-	L	L	L
Estimated median FWI, from GISS 1980 scenario						
May	L	M	-	L	L	-
June	M	M	M	H	M	M
July	M	H	M	H	M	M
Aug	M	M	-	M	L	L
Sept	L	L	-	L	L	L

Conclusions:

When compared with baseline scenarios, both models forecast increases in fire danger for most of the Mackenzie Basin, given a doubling in atmospheric CO2. These increases are projected to occur in the first half of the fire season: May for GISS, May-June for CCC. Even if the fire danger categories for monthly medians do not change substantially, high and extreme daily values could become more frequent and widespread as the distribution shifts to the right by a few units. It would take only two or three more such days per month to increase the risk of severe fire outbreaks (e.g. northern Manitoba in 1989).

This study assumes that daily Fire Weather Index values will be distributed along a normal curve, even during high fire years like 1989 and 1995. The issue of curve skewness is particularly important, since any fires that start during periods of high or extreme fire susceptibility are likely to spread quickly and cause the most damage. No provision has been made here for skewed distribution, favouring either low or high fire danger.

Admittedly, there are more problems with this forecasting method. Interpolation is slightly less risky than extrapolation beyond observed values, but fundamental assumptions must be recognized. Relying on present climate-fire relationships is only reasonable if the ignition probabilities remain similar in the future. Changes in the frequency of storm fronts and secondary pressure cells, either as a result of global

warming or independent of it, could affect the frequency of lightning and droughts. Since most fire starts and area burned in the Mackenzie region are attributable to lightning (Ramsey and Higgins 1991), this could have a significant impact on the fire regime. Fire size and behaviour are influenced by factors such as fuel availability, which in turn are related to climate through vegetation health and forest dynamics. Some of these factors are discussed by other participants in the MBIS project.

Finally, the relationships between human activity and fire, through accidental or deliberate fire starts, and management strategies such as suppression or controlled burning, are still not fully understood. All of these issues are likely to play a role in determining the Mackenzie Basin's fire regime during the next century, and what impacts it will have on the environments and communities of the region.

Acknowledgments:

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Appendix I Regression equations used in study

Month	Station names	Station ID	Indep var	Constant	Precip	Temp	N	R-sq	Std err	F-ratio	P
May	Chetwynd BCFS	1181509	lnP and lnT	-2.604	-3.516	11.733	13	0.307	6.178	2.21	0.16
May	Fort St. John A	1183000	lnP and lnT	-13.421	-4.447	18.183	21	0.527	5.307	10.02	0.001
May	Germansen Landing	1183090	lnP and lnT	15.148	-5.981	6.355	14	0.745	2.492	16.087	0.001
May	Mackenzie A	1184790	lnP and lnT	16.196	-4.97	3.801	19	0.653	2.476	15.079	0
May	Dease Lake	1192340	lnP and lnT	5.644	-4.043	7.035	20	0.64	2.21	15.115	0
May	Fort Nelson A	1192940	lnP and lnT	5.705	-5.664	10.777	20	0.444	4.278	6.795	0.007
May	Watson Lake A	2101200	lnP and lnT	14.088	-3.238	1.503	19	0.441	2.872	6.299	0.01
May	Whitehorse	2101300	lnP and lnT	3.607	-2.792	6.805	19	0.342	4.075	4.159	0.035
May	Fort Resolution A	2202000	lnP and lnT	-2.1	-1.54	6.719	22	0.181	4.029	2.1	0.15
May	Fort Simpson A	2202101	lnP and lnT	-8.604	-3.891	14.212	26	0.745	3.27	33.6	0
May	Fort Smith A	2202200	lnP and lnT	-2.28	-2.483	10.892	36	0.396	4.696	10.803	0
May	Hay River A	2202400	lnP and lnT	-1.992	-0.625	5.524	37	0.432	3.488	12.908	0
May	Norman Wells A	2202800	lnP and lnT	4.694	-1.905	3.558	35	0.362	2.654	9.069	0.001
May	Yellowknife A	2204100	lnP and lnT	0.462	-0.946	5.582	36	0.524	2.905	18.148	0
May	Yellowknife A	2204100	lnP and lnK	-1942.063	-0.905	346.653	38	0.63	2.546	29.757	0
May	Inuvik A	2202570	lnP and lnK	-260.35	-0.445	46.85	27	0.213	0.983	3.254	0.056
May	Chetwynd BCFS	1181509	P and T (AES)	3.281	-0.111	1.374	13	0.348	5.989	2.673	0.118
May	Fort St. John A	1183000	P and T (AES)	-4.98	-0.111	2.238	21	0.489	5.513	8.623	0.002
May	Germansen Landing	1183090	P and T (AES)	4.144	-0.111	0.961	14	0.564	3.26	7.11	0.01
May	Mackenzie A	1184790	P and T (AES)	6.542	-0.087	0.421	19	0.434	3.163	6.14	0.011
May	Dease Lake	1192340	P and T (AES)	1.914	-0.154	1.318	20	0.466	2.692	7.41	0.005
May	Fort Nelson A	1192940	P and T (AES)	3.047	-0.103	1.104	20	0.464	4.203	7.345	0.005
May	Watson Lake A	2101200	P and T (AES)	8.183	-0.081	0.113	19	0.366	3.057	4.618	0.026
May	Whitehorse	2101300	P and T (AES)	8.285	-0.238	0.773	19	0.356	4.032	4.416	0.03
May	Fort Resolution A	2202000	P and T (AES)	0.808	-0.085	1.062	22	0.269	3.808	3.488	0.051
May	Fort Simpson A	2202101	P and T (AES)	-2.85	-0.14	1.975	26	0.651	3.825	21.47	0
May	Fort Smith A	2202200	P and T (AES)	1.468	-0.115	1.755	36	0.475	4.378	14.907	0
May	Hay River A	2202400	P and T (AES)	-2.833	-0.001	1.446	37	0.582	2.991	23.66	0
May	Norman Wells A	2202800	P and T (AES)	3.014	-0.085	0.706	35	0.272	2.834	5.981	0.006
May	Yellowknife A	2204100	P and T (AES)	2.051	-0.09	1.251	38	0.678	2.375	36.769	0
May	Yellowknife A	2204100	P and K (AES)	-339.613	-0.09	1.251	38	0.678	2.375	36.769	0
May	Inuvik A	2202570	P and T (AES)	1.681	-0.019	0.177	27	0.164	1.014	2.351	0.117
May	Inuvik A	2202570	P and K (AES)	-46.713	-0.019	0.177	27	0.164	1.014	2.351	0.117
Jun	Chetwynd BCFS	1181509	lnP and lnT	-24.925	-6.555	23.394	13	0.732	4.053	13.658	0.001
Jun	Fort St. John A	1183000	lnP and lnT	-23.409	-5.456	21.058	21	0.675	3.229	18.684	0
Jun	Germansen Landing	1183090	lnP and lnT	29.949	-9.239	6.163	19	0.661	3.406	15.582	0
Jun	Mackenzie A	1184790	lnP and lnT	-26.603	-4.745	21.612	20	0.349	6.129	4.565	0.026
Jun	Dease Lake	1192340	lnP and lnT	-1.492	-5.076	11.216	20	0.74	2.851	24.229	0
Jun	Fort Nelson A	1192940	lnP and lnT	-4.628	-6.317	14.285	20	0.686	3.102	18.558	0
Jun	Watson Lake A	2101200	lnP and lnT	34.105	-7.859	2.933	20	0.452	5.491	7.006	0.006
Jun	Whitehorse	2101300	lnP and lnT	28.907	-5.521	1.493	20	0.233	6.746	2.586	0.105
Jun	Fort Resolution A	2202000	lnP and lnT	1.445	-3.261	7.937	24	0.372	3.947	6.21	0.008
Jun	Fort Simpson A	2202101	lnP and lnT	-19.135	-5.508	18.727	27	0.613	3.159	19.031	0
Jun	Fort Smith A	2202200	lnP and lnT	19.503	-8.941	10.23	36	0.776	3.837	57.268	0
Jun	Hay River A	2202400	lnP and lnT	-18.645	-2.938	14.453	37	0.628	2.566	28.719	0
Jun	Inuvik A	2202570	lnP and lnT	-7.247	-2.439	9.412	30	0.64	2.942	23.965	0
Jun	Norman Wells A	2202800	lnP and lnT	-5.935	-4.974	13.045	34	0.679	2.996	32.746	0
Jun	Yellowknife A	2204100	lnP and lnT	-30.981	-2.59	20.678	38	0.422	4.387	12.763	0
Jun	Chetwynd BCFS	1181509	P and T (AES)	-6.485	-0.118	1.762	13	0.746	3.948	14.66	0.001
Jun	Fort St. John A	1183000	P and T (AES)	-9.164	-0.084	1.787	21	0.579	3.676	12.36	0
Jun	Germansen Landing	1183090	P and T (AES)	13.512	-0.142	0.265	19	0.472	4.251	7.138	0.006
Jun	Mackenzie A	1184790	P and T (AES)	-8.388	-0.088	1.835	20	0.31	6.31	3.827	0.042
Jun	Dease Lake	1192340	P and T (AES)	1.403	-0.176	1.234	20	0.743	2.838	24.532	0
Jun	Fort Nelson A	1192940	P and T (AES)	2.284	-0.096	0.843	20	0.613	3.443	13.453	0
Jun	Watson Lake A	2101200	P and T (AES)	21.25	-0.193	0.028	20	0.495	5.272	8.322	0.003
Jun	Whitehorse	2101300	P and T (AES)	16.066	-0.18	0.349	20	0.176	6.993	1.818	0.193
Jun	Fort Resolution A	2202000	P and T (AES)	4.865	-0.114	0.787	24	0.459	3.663	8.899	0.002

Jun	Fort Simpson A	2202101	P and T (AES)	-7.5	-0.081	1.531	27	0.45	3.767	9.82	0.001
Jun	Fort Smith A	2202200	P and T (AES)	9.539	-0.233	1.115	36	0.754	4.023	50.613	0
Jun	Hay River A	2202400	P and T (AES)	-4.159	-0.096	1.276	37	0.569	2.763	22.435	0
Jun	Inuvik A	2202570	P and T (AES)	-0.197	-0.153	1.119	30	0.59	3.138	19.414	0
Jun	Norman Wells A	2202800	P and T (AES)	11.42	-0.16	0.455	34	0.486	3.789	14.657	0
Jun	Yellowknife A	2204100	P and T (AES)	-3.011	-0.145	1.619	38	0.451	4.275	14.376	0
Jul	Chetwynd BCFS	1181509	lnP and lnT	13.284	-8.307	11.011	13	0.798	3.354	19.796	0
Jul	Fort St. John A	1183000	lnP and lnT	29.516	-6.162	1.501	21	0.678	2.989	18.99	0
Jul	Germansen Landing	1183090	lnP and lnT	-3.384	-6.023	13.315	20	0.497	5.085	8.396	0.003
Jul	Mackenzie A	1184790	lnP and lnT	-72.131	-6.455	40.213	20	0.469	6.082	7.508	0.005
Jul	Dease Lake	1192340	lnP and lnT	12.034	-6.149	6.932	20	0.656	2.546	16.178	0
Jul	Fort Nelson A	1192940	lnP and lnT	31.644	-8.312	3.745	20	0.738	3.436	24.004	0
Jul	Watson Lake A	2101200	lnP and lnT	96.514	-10.654	-16.565	20	0.687	5.605	18.631	0
Jul	Whitehorse	2101300	lnP and lnT	51.69	-10.04	-1.794	20	0.584	6.451	11.934	0.001
Jul	Fort Resolution A	2202000	lnP and lnT	25.121	-7.907	5.528	23	0.595	3.863	14.717	0
Jul	Fort Simpson A	2202101	lnP and lnT	-24.63	-6.991	21.924	27	0.647	3.655	21.998	0
Jul	Fort Smith A	2202200	lnP and lnT	5.333	-7.991	14.213	36	0.533	4.841	18.861	0
Jul	Hay River A	2202400	lnP and lnT	-6.438	-4.21	10.656	37	0.515	3.14	18.051	0
Jul	Inuvik A	2202570	lnP and lnT	-15.859	-4.472	15.265	30	0.611	3.078	21.168	0
Jul	Norman Wells A	2202800	lnP and lnT	2.238	-6.089	10.403	34	0.526	3.556	17.233	0
Jul	Yellowknife A	2204100	lnP and lnT	-22.264	-6.405	21.055	38	0.553	4.886	21.629	0
Jul	Chetwynd BCFS	1181509	P and T (AES)	0.24	-0.119	1.156	13	0.669	4.3	10.089	0.004
Jul	Fort St. John A	1183000	P and T (AES)	6.344	-0.083	0.508	21	0.554	3.519	11.188	0.001
Jul	Germansen Landing	1183090	P and T (AES)	-4.274	-0.116	1.4	20	0.499	5.075	8.463	0.003
Jul	Mackenzie A	1184790	P and T (AES)	-24.698	-0.125	2.91	20	0.533	5.705	9.693	0.002
Jul	Dease Lake	1192340	P and T (AES)	1.96	-0.103	0.739	20	0.581	2.808	11.791	0.001
Jul	Fort Nelson A	1192940	P and T (AES)	-5.595	-0.082	1.151	20	0.593	4.284	12.406	0
Jul	Watson Lake A	2101200	P and T (AES)	35.203	-0.202	-0.835	20	0.568	6.583	11.168	0.001
Jul	Whitehorse	2101300	P and T (AES)	15.541	-0.224	0.392	20	0.423	7.595	6.241	0.009
Jul	Fort Resolution A	2202000	P and T (AES)	12.515	-0.135	0.3	23	0.559	4.031	12.696	0
Jul	Fort Simpson A	2202101	P and T (AES)	-10.088	-0.139	1.659	27	0.614	3.824	19.068	0
Jul	Fort Smith A	2202200	P and T (AES)	12.175	-0.172	0.707	36	0.549	4.761	20.054	0
Jul	Hay River A	2202400	P and T (AES)	3.764	-0.109	0.567	37	0.526	3.104	18.883	0
Jul	Inuvik A	2202570	P and T (AES)	-3.126	-0.136	1.227	30	0.553	3.297	16.711	0
Jul	Norman Wells A	2202800	P and T (AES)	4.077	-0.119	0.618	34	0.477	3.735	14.161	0
Jul	Yellowknife A	2204100	P and T (AES)	-0.8	-0.185	1.377	38	0.523	5.047	19.181	0
Aug	Chetwynd BCFS	1181509	lnP and lnT	-20.975	-5.706	19.456	12	0.514	5.42	4.762	0.039
Aug	Fort St. John A	1183000	lnP and lnT	-57.235	-4.762	31.621	21	0.574	4.762	12.151	0
Aug	Germansen Landing	1183090	lnP and lnT	21.564	-11.466	11.436	20	0.773	3.608	28.865	0
Aug	Mackenzie A	1184790	lnP and lnT	-62.51	-6.551	37.103	20	0.595	6.178	12.483	0
Aug	Dease Lake	1192340	lnP and lnT	-27.682	-1.923	15.923	20	0.212	4.176	2.283	0.132
Aug	Fort Nelson A	1192940	lnP and lnT	-56.806	-5.574	31.913	20	0.53	4.449	9.585	0.002
Aug	Watson Lake A	2101200	lnP and lnT	-53.465	-1.031	26.314	20	0.15	7.907	1.495	0.252
Aug	Whitehorse	2101300	lnP and lnT	-35.699	-3.728	23.76	20	0.275	7.394	3.229	0.065
Aug	Fort Resolution A	2202000	lnP and lnT	32.515	-3.145	-4.542	23	0.074	5.478	0.803	0.462
Aug	Fort Simpson A	2202101	lnP and lnT	0.557	-5.96	11.068	25	0.638	3.146	19.361	0
Aug	Fort Smith A	2202200	lnP and lnT	25.787	-5.993	2.319	36	0.457	4.663	13.906	0
Aug	Hay River A	2202400	lnP and lnT	-18.189	-2.361	12.339	37	0.409	2.993	11.769	0
Aug	Inuvik A	2202570	lnP and lnT	10.737	-4.272	3.872	30	0.384	3.621	8.413	0.001
Aug	Norman Wells A	2202800	lnP and lnT	19.467	-4.261	0.304	33	0.666	2.733	29.932	0
Aug	Yellowknife A	2204100	lnP and lnT	-1.929	-4.237	10.18	38	0.563	3.732	22.561	0
Aug	Chetwynd BCFS	1181509	P and T (AES)	-11.474	-0.066	1.668	12	0.473	5.647	4.034	0.056
Aug	Fort St. John A	1183000	P and T (AES)	-23.167	-0.078	2.512	21	0.546	4.918	10.83	0.001
Aug	Germansen Landing	1183090	P and T (AES)	11.633	-0.294	0.787	20	0.721	3.995	21.971	0
Aug	Mackenzie A	1184790	P and T (AES)	-15.707	-0.182	2.572	20	0.595	6.181	12.464	0
Aug	Dease Lake	1192340	P and T (AES)	-13.323	-0.01	1.517	20	0.194	4.222	2.05	0.159
Aug	Fort Nelson A	1192940	P and T (AES)	-18.034	-0.098	2.083	20	0.506	4.563	8.692	0.003
Aug	Watson Lake A	2101200	P and T (AES)	-19.615	0.013	2.245	20	0.141	7.946	1.396	0.274
Aug	Whitehorse	2101300	P and T (AES)	-14.166	-0.059	2.217	20	0.217	7.683	2.362	0.124
Aug	Fort Resolution A	2202000	P and T (AES)	21.451	-0.117	-0.515	23	0.144	5.269	1.678	0.212

Aug	Fort Simpson A	2202101	P and T (AES)	4.071	-0.124	0.688	25	0.593	3.334	16.043	0
Aug	Fort Smith A	2202200	P and T (AES)	12.566	-0.16	0.347	36	0.464	4.635	14.28	0
Aug	Hay River A	2202400	P and T (AES)	-3.716	-0.062	0.886	37	0.314	3.224	7.793	0.002
Aug	Inuvik A	2202570	P and T (AES)	5.263	-0.071	0.208	30	0.239	4.025	4.237	0.025
Aug	Norman Wells A	2202800	P and T (AES)	9.136	-0.101	0.049	33	0.482	3.404	13.961	0
Aug	Yellowknife A	2204100	P and T (AES)	5.588	-0.1	0.655	38	0.476	4.087	15.904	0
Sep	Chetwynd BCFS	1181509	lnP and lnT	16.764	-4.02	1.17	12	0.782	2.601	16.13	0.001
Sep	Fort St. John A	1183000	lnP and lnT	8.379	-3.465	4.158	21	0.796	2.239	35.122	0
Sep	Germansen Landing	1183090	lnP and lnT	4.112	-3.077	5.071	18	0.416	3.293	5.341	0.018
Sep	Dease Lake	1192340	lnP and lnT	-1.145	-0.692	2.569	20	0.245	0.943	2.759	0.092
Sep	Fort Nelson A	1192940	lnP and lnT	10.275	-2.992	2.004	19	0.503	2.557	8.091	0.004
Sep	Watson Lake A	2101200	lnP and lnT	39.853	-1.988	-13.875	20	0.136	5.812	1.341	0.288
Sep	Whitehorse	2101300	lnP and lnT	40.927	-5.268	-8.005	20	0.218	5.424	2.369	0.124
Sep	Fort Resolution A	2202000	lnP and lnT	0.265	-1.172	3.959	15	0.1	3.566	0.665	0.532
Sep	Fort Simpson A	2202101	lnP and lnT	9.548	-2.931	2.669	27	0.339	3.344	6.145	0.007
Sep	Fort Smith A	2202200	lnP and lnT	8.581	-3.216	3.587	35	0.364	2.359	9.143	0.001
Sep	Hay River A	2202400	lnP and lnT	11.766	-4.197	3.068	37	0.668	2.198	34.246	0
Sep	Inuvik A	2202570	lnP and lnT	5.834	-1.443	0.116	28	0.317	1.58	5.803	0.009
Sep	Norman Wells A	2202800	lnP and lnT	0.28	-1.214	3.642	33	0.334	2.035	7.514	0.002
Sep	Yellowknife A	2204100	lnP and lnT	13.627	-2.266	-1.221	38	0.329	2.31	8.586	0.001
Sep	Inuvik A	2202570	lnP and lnK	-94.739	-1.48	17.927	30	0.344	1.521	7.083	0.003
Sep	Chetwynd BCFS	1181509	P and T (AES)	8.984	-0.147	0.289	12	0.583	3.597	6.283	0.02
Sep	Fort St. John A	1183000	P and T (AES)	-0.133	-0.078	0.974	21	0.683	2.792	19.391	0
Sep	Germansen Landing	1183090	P and T (AES)	0.732	-0.088	0.818	18	0.29	3.631	3.06	0.077
Sep	Dease Lake	1192340	P and T (AES)	-1.256	-0.009	0.406	20	0.211	0.965	2.267	0.134
Sep	Fort Nelson A	1192940	P and T (AES)	5.403	-0.087	0.26	19	0.515	2.526	8.488	0.003
Sep	Watson Lake A	2101200	P and T (AES)	16.067	0.005	-1.541	20	0.102	5.927	0.962	0.402
Sep	Whitehorse	2101300	P and T (AES)	24.457	-0.213	-1.374	20	0.281	5.2	3.329	0.06
Sep	Fort Resolution A	2202000	P and T (AES)	-0.793	-0.036	0.815	15	0.177	3.41	1.29	0.311
Sep	Fort Simpson A	2202101	P and T (AES)	5.413	-0.105	0.427	27	0.366	3.274	6.93	0.004
Sep	Fort Smith A	2202200	P and T (AES)	3.735	-0.098	0.569	35	0.358	2.369	8.929	0.001
Sep	Hay River A	2202400	P and T (AES)	2.076	-0.089	0.597	37	0.422	2.901	12.419	0
Sep	Inuvik A	2202570	P and T (AES)	2.651	-0.05	0.061	30	0.154	1.728	2.464	0.104
Sep	Inuvik A	2202570	P and K (AES)	-13.99	-0.05	0.061	30	0.154	1.728	2.464	0.104
Sep	Norman Wells A	2202800	P and T (AES)	-0.694	-0.026	0.699	33	0.325	2.048	7.236	0.003
Sep	Yellowknife A	2204100	P and T (AES)	7.51	-0.073	-0.194	38	0.171	2.568	3.603	0.038

* "K" signifies temperature in Kelvin, to avoid negative values

Appendix II Projected median FWI values

Station names	ID number	G1980	G1990	G2000	G2010	G2020	G2030	G2040	G2050	5180n	CCC2x	N	R-sq	f-ratio	P
MAY															
Norman Wells A	2202800	4.7	6.1	5.8	5.8	5.9	6.4	6.9	7.0	5.3	6.6	35	0.36	9.07	0.001
Yellowknife A	2204100	5.7	8.0	7.8	7.6	8.2	8.9	9.9	10.3	6.4	10.3	38	0.63	29.76	0.000
Fort Simpson A	2202101	5.8	9.5	8.8	8.7	9.3	10.3	11.9	12.3	7.1	12.4	26	0.75	33.60	0.000
Hay River A	2202400	5.1	6.8	6.6	6.5	6.9	7.4	7.9	8.1	5.7	8.4	37	0.43	12.91	0.000
Whitehorse	2101300	8.5	10.5	10.2	10.2	10.4	11.0	11.9	12.1	9.3	11.4	19	0.34	4.16	0.035
Watson Lake A	2101200	5.5	6.3	5.9	6.2	5.9	6.3	6.7	6.9	6.1	6.6	19	0.44	6.30	0.010
Fort Smith A	2202200	11.1	13.7	13.2	13.2	13.6	14.4	15.4	15.7	12.0	15.1	36	0.40	10.80	0.000
Fort Nelson A	1192940	7.5	10.3	9.4	9.7	9.6	10.5	11.8	12.2	8.9	12.1	20	0.44	6.80	0.007
Dease Lake	1192340	4.1	6.6	6.0	6.1	6.2	6.9	7.9	8.3	5.2	7.9	20	0.64	15.12	0.000
Fort St. John A	1183000	12.3	11.9	11.4	12.7	13.3	14.0	14.8	15.9	11.1	18.2	21	0.53	10.02	0.001
Germansen Landing	1183090	7.3	7.1	6.1	7.4	7.5	7.7	8.0	8.2	6.5	9.0	14	0.75	16.09	0.001
Mackenzie A	1184790	6.4	6.3	5.6	6.6	6.5	6.7	6.9	6.8	6.1	7.6	19	0.65	15.08	0.000

JUNE															
Inuvik A	2202570	6.6	7.9	7.8	8.1	8.1	9.4	9.3	9.3	6.8	8.6	30	0.64	23.97	0.000
Norman Wells A	2202800	10.3	10.0	10.7	10.5	10.9	11.3	11.4	12.4	10.4	14.4	34	0.68	32.75	0.000
Yellowknife A	2204100	14.6	14.4	15.2	15.2	15.7	16.1	16.5	18.2	14.6	20.6	38	0.42	12.76	0.000
Fort Simpson A	2202101	9.2	9.0	9.7	9.6	10.1	10.6	10.9	12.4	9.3	15.1	27	0.61	19.03	0.000
Fort Resolution A	2202000	11.1	11.0	11.5	11.4	11.6	12.0	11.9	12.7	11.3	13.8	24	0.37	6.21	0.008
Hay River A	2202400	7.5	7.4	7.9	8.0	8.3	8.7	9.0	10.3	7.6	13.1	37	0.63	28.72	0.000
Watson Lake A	2101200	10.1	9.8	10.4	10.2	10.5	10.7	10.4	10.8	10.5	11.3	20	0.45	7.01	0.006
Fort Smith A	2202200	12.4	12.0	13.1	12.7	13.3	13.7	13.4	14.4	13.0	16.8	36	0.78	57.27	0.000
Fort Nelson A	1192940	6.5	6.1	6.9	6.8	7.3	7.7	7.7	8.8	6.7	11.0	20	0.69	18.56	0.000
Dease Lake	1192340	5.4	5.2	5.9	5.9	6.2	6.7	6.8	8.0	5.6	9.8	20	0.74	24.23	0.000
Fort St. John A	1183000	8.8	9.3	7.9	9.2	8.8	11.0	11.4	11.8	7.7	14.3	21	0.68	18.68	0.000
Germansen Landing	1183090	8.6	8.3	7.6	8.7	7.4	9.6	9.3	8.8	8.0	9.3	19	0.66	15.58	0.000
Chetwynd BCFS	1181509	7.9	8.5	7.0	8.3	7.7	10.4	10.9	11.2	6.8	14.2	13	0.73	13.66	0.001
Mackenzie A	1184790	9.4	10.0	8.7	9.9	9.5	11.7	12.3	12.8	8.4	14.7	20	0.35	4.57	0.026
JULY															
Inuvik A	2202570	8.2	7.6	9.1	8.8	8.5	8.3	7.7	8.5	8.3	9.2	30	0.61	21.17	0.000
Norman Wells A	2202800	7.0	7.0	7.7	7.0	7.8	8.5	7.9	8.7	6.8	8.7	34	0.53	17.23	0.000
Yellowknife A	2204100	14.5	14.8	15.6	14.9	16.4	17.2	16.7	17.9	13.9	16.9	38	0.55	21.63	0.000
Fort Simpson A	2202101	9.1	9.3	10.1	9.4	11.1	11.8	11.3	12.5	8.3	12.5	27	0.65	22.00	0.000
Fort Resolution A	2202000	10.6	10.4	11.3	10.1	11.0	11.8	11.0	11.6	10.6	11.1	23	0.60	14.72	0.000
Hay River A	2202400	7.0	7.1	7.6	7.1	7.9	8.5	8.1	8.8	6.7	8.8	37	0.52	18.05	0.000
Whitehorse	2101300	11.5	10.6	12.0	10.0	10.7	11.9	10.4	10.8	11.6	9.0	20	0.58	11.93	0.001
Watson Lake A	2101200	7.8	6.7	8.3	5.8	5.6	6.9	5.0	4.8	8.6	4.2	20	0.69	18.63	0.000
Fort Smith A	2202200	13.0	13.0	13.9	12.8	14.1	15.0	14.3	15.2	12.6	15.1	36	0.53	18.86	0.000
Fort Nelson A	1192940	5.4	5.0	6.1	4.6	5.4	6.4	5.3	5.9	5.3	6.7	20	0.74	24.00	0.000
Dease Lake	1192340	4.5	4.4	5.1	4.2	5.2	5.9	5.3	5.9	4.2	5.5	20	0.66	16.18	0.000
Fort St. John A	1183000	7.6	7.5	6.5	6.8	7.2	8.2	7.2	6.6	7.1	6.3	21	0.68	18.99	0.000
Germansen Landing	1183090	8.1	8.0	6.8	7.3	8.0	10.0	9.4	8.8	6.6	8.4	20	0.50	8.40	0.003
Chetwynd BCFS	1181509	8.5	8.4	7.0	7.4	8.1	10.2	9.2	8.4	7.1	8.6	13	0.80	19.80	0.000
Mackenzie A	1184790	12.7	12.6	10.9	12.1	13.5	17.4	17.5	17.0	9.2	17.0	20	0.47	7.51	0.005
AUGUST															
Inuvik A	2202570	1.5	2.0	2.3	2.4	2.5	2.6	2.2	3.2	2.0	2.8	30	0.38	8.41	0.001
Norman Wells A	2202800	3.0	2.6	3.0	2.2	2.8	2.7	2.6	2.7	2.8	2.2	33	0.67	29.93	0.000
Yellowknife A	2204100	8.1	8.1	8.0	8.1	9.0	9.0	9.5	10.4	8.0	9.8	38	0.56	22.56	0.000
Fort Simpson A	2202101	7.1	7.0	7.0	6.7	7.9	7.9	8.3	9.2	6.9	8.1	25	0.64	19.36	0.000
Hay River A	2202400	6.0	6.2	5.7	6.5	7.0	7.1	7.8	8.7	6.0	8.2	37	0.41	11.77	0.000
Fort Smith A	2202200	9.7	9.3	9.7	8.8	9.6	9.6	9.5	9.7	9.4	9.7	36	0.46	13.91	0.000
Fort Nelson A	1192940	1.9	2.6	1.3	3.4	4.9	5.3	7.0	9.7	1.9	6.5	20	0.53	9.59	0.002
Fort St. John A	1183000	10.7	10.5	11.3	10.9	10.9	15.9	13.8	15.9	8.5	14.1	21	0.57	12.15	0.000
Germansen Landing	1183090	8.2	6.3	7.4	6.6	5.8	11.3	6.9	8.4	6.5	7.3	20	0.77	28.87	0.000
Chetwynd BCFS	1181509	9.1	8.5	9.2	8.8	8.5	12.7	10.4	11.9	7.5	10.5	12	0.51	4.76	0.039
Mackenzie A	1184790	13.6	13.2	14.1	13.7	13.6	19.9	17.0	19.6	11.0	16.3	20	0.60	12.48	0.000
SEPTEMBER															
Inuvik A	2202570	1.3	1.3	1.5	1.3	1.5	1.4	1.6	1.4	1.3	1.3	30	0.34	7.08	0.003
Norman Wells A	2202800	3.0	3.6	3.9	3.6	3.9	3.9	4.6	4.5	2.8	4.0	33	0.33	7.51	0.002
Yellowknife A	2204100	3.5	3.0	3.4	2.9	3.4	2.9	3.0	2.8	3.5	2.8	38	0.33	8.59	0.001
Fort Simpson A	2202101	4.6	4.7	5.3	4.6	5.3	4.9	5.6	5.4	4.4	5.1	27	0.34	6.15	0.007
Hay River A	2202400	2.6	2.6	3.3	2.4	3.5	2.8	3.8	3.3	2.5	3.3	37	0.67	34.25	0.000
Fort Smith A	2202200	4.1	4.3	4.9	4.1	5.0	4.5	5.4	5.1	3.9	5.0	35	0.36	9.14	0.001
Fort Nelson A	1192940	3.6	3.6	4.0	3.4	4.1	3.7	4.3	4.0	3.5	3.8	19	0.50	8.09	0.004
Fort St. John A	1183000	5.6	4.4	4.6	5.7	5.9	4.7	5.8	7.4	5.0	5.8	21	0.80	35.12	0.000
Germansen Landing	1183090	3.5	2.6	2.9	3.8	4.1	3.3	4.3	5.8	3.0	4.0	18	0.42	5.34	0.018
Chetwynd BCFS	1181509	4.7	3.3	3.2	4.5	4.5	2.7	4.0	5.4	4.0	3.9	12	0.78	16.13	0.001

White Pine Weevil Hazard under GISS Climate Change Scenarios in the Mackenzie Basin Using Radiosonde Derived Lapse Rates

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Abstract

The white pine weevil, Pissodes strobi, hampers spruce and pine regeneration by mining and killing leaders, resulting in crooks and forks as laterals become dominant. The weevil requires 785 degree days accumulated above 7.2°C during the growing season to complete development. Maps of accumulated degree days are presented to indicate the potential range of the weevil under present and climate change scenarios. Monthly means of temperature were extrapolated from Environment Canada climate stations throughout the Mackenzie Basin using latitudinally varying radiosonde derived lapse rates and an elevation model to create a temperature surface of the basin for the present climate (1951–1980 normals). Radiosonde lapse rates varied by pressure level, month and latitude. The largest lapse rate variation was seen in the surface to 850 mb layer where rates varied from -0.006°C/m to 0.008°C/m reflecting the strength of the arctic inversion. The 1951–1980 mean monthly temperature surfaces were adjusted using the Goddard Institute for Space Studies (GISS) General Circulation Model climate change temperature increase for 2050. Daily air temperature data were generated fitting a cosine curve through the monthly temperature means. The air temperature data were increased by 1°C because leader temperatures are greater than air temperatures on sunny days. On a daily basis, degree days were calculated and accumulated using leader temperatures (adjusted air temperatures) for the present and year 2050 climates. The coverages of accumulated degree days were classified to indicate high, medium and low weevil hazards. With increased temperatures, there will be sufficient growing season heat to allow the spruce weevil to expand its range northward in latitude and upward in elevation to occupy nearly all the areas presently forested with white spruce in the Mackenzie Basin.

Introduction

The white pine, or spruce weevil, *Pissodes strobi,* Peck is presently a significant forest pest in the southern portion of the Mackenzie Basin. In British Columbia, the insect is responsible for up to 500 million dollars of annual damage (Forestry Canada, 1993). In the Mackenzie Basin, the spruce weevil, attacks jack pine, *Pinus banksiana* Lamb, white spruce, *Picea glauca* (Monench) Voss; Englemann spruce, *Picea engelmannii* Parry; and to a minor degree black spruce, *Picea mariana* (Mill.) B.S.P (Drouin, 1981, Humble *et al.,* 1994). During the late spring, the weevil lays eggs in the previous year's leader of the tree. During the summer, the eggs become larvae which feed on the phloem of the leader, resulting in leader death. Leader death does not kill the tree but results in crooks or forks as lateral branches become dominant (Fink *et al.,* 1989). Spruce weevil induced deformities reduce log quality and value, reduce height growth and increase the length of crop rotation (Alfaro, 1989). With repeated leader death, weevil attacked spruce may be overtopped and out competed by other tree species (Alfaro, 1982), resulting in a change in species composition.

Temperature is a major environmental factor limiting control of the geographic distribution of forest pests. Accumulated heat can be quantified in terms of degree days above a threshold temperature. McMullen (1976) determined that 785 degree days above a threshold of 7.2 °C are required during the growing season for weevil development (egg, larvae, pupae and adult) on white spruce in the interior of British Columbia.

Previous studies have suggested that global warming may have a significant impact on the distribution of insect pests and disease vectors (Porter *et al.,* 1991; Sutherst *et al.,* 1995; Jetten *et al.,* 1996). A preliminary examination of the weevil hazard in the Mackenzie Basin was completed by Sieben *et al.* (1994), but was unable to relate the results to the Mackenzie Basin Impacts Study (MBIS) warming scenarios because of problems in the MBIS data. This study corrects the MBIS data-set problem and investigates the potential increase in weevil hazard on white spruce due to climatic warming in the Mackenzie Basin using the Goddard Institute for Space Studies (GISS) warming scenarios.

Methods

The spruce weevil develops inside the leader. Spittlehouse *et al.* (1994) found that daily average leader temperatures are greater than air temperatures on sunny days and average approximately 1°C above air temperatures during the summer months in the interior of British Columbia. Throughout the Mackenzie Basin, daily average leader temperatures are only above the 7.2°C weevil development threshold between May and September even with climate change. The energy available for weevil development (heat sum) during this period is given by:

$$\text{Degree Day Heat Sum} = \sum_{\text{May 1}}^{\text{Sept 30}} \text{mean daily leader temperature} - 7.2 \qquad (1)$$

where the mean daily leader temperature (°C) is given by [{(max air temp. + min air temp.)/2} + 1], and the threshold temperature is 7.2°C.

Smith and Cohen (1993) utilized Environment Canada station data to construct a matrix of 3800 interpolated grid points throughout the basin (**Figure 1**). For each grid point Smith and Cohen provided monthly temperature means derived from the 1951–1980 normals and predicted monthly means under climate warming scenarios. Computation of degree day heat sums (**Equation 1**) requires daily temperature data, thus daily data had to be generated before degree day heat sums could be calculated. Daily data were generated by fitting a cosine curve (**Figure 2**) through the monthly mean temperatures. The cosine curve fluctuated around the yearly average of monthly temperatures and had an amplitude approximately equal to the difference between the July temperature and yearly average temperature. Sieben *et al.* (1994) present formula for calculating daily temperatures using the cosine methodology. The excellent agreement with degree day heat sums calculated using actual degree day data can be seen in **Figure 3**.

Using the data from Smith and Cohen (1993), SAS software (SAS Institute 1996) was utilized to apply the cosine methodology and **Equation 1** to generate degree day heat sums for every gridded MBIS data point. The degree day values were read into SURFER software package (Golden Software, 1995) to produce a matrix of the 1951-1980 May to September leader degree days above 7.2°C. The matrix of leader degree days was imported into the IDRISI Geographical Information System, (Clark University Graduate School of Geography, 1995) to classify the surface into three hazard classes to produce final weevil hazard maps.

Locations with an average heat sum of 720 or more degree days will in some years have a heat sum above the 785 degree day development threshold due to yearly climatic variability. To account for this year to year variability, three hazard classes were used to produce hazard rating maps: high (>800 degree days), medium (720-800 degree days), and low (< 720 degree days). No weevils should be able to complete their life cycle in areas in the low category in any year. Increasing numbers of weevils should be able to complete their life cycles in the medium and high hazard classes. The medium hazard class may have enough heat for weevil development in some years, while there should be enough heat in the high hazard class in all years.

Examination of the weevil hazard map for the baseline 1951-1980 raised concerns regarding the MBIS gridded data temperature data set. Specifically, Smith and Cohen

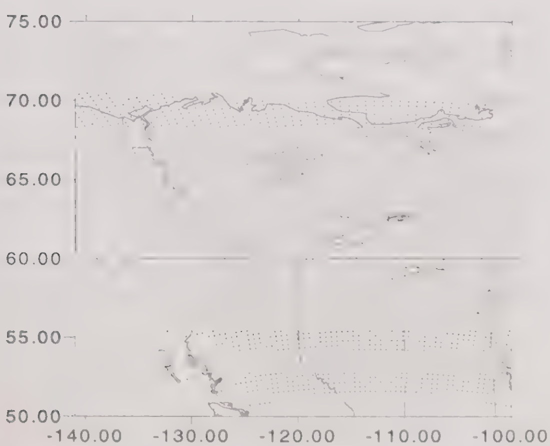

Figure 1. Mackenzie Basin gridded monthly temperature grid points utilized by Smith and Cohen (1993).

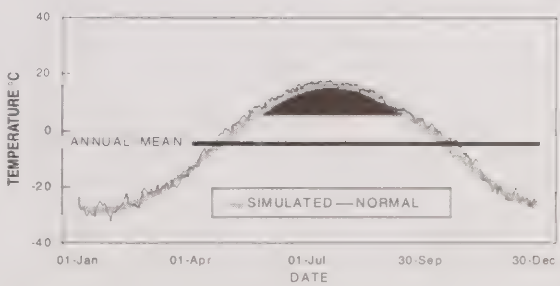

Figure 2. Comparison of 1951-1980 normal (average) daily and simulated daily temperatures for Yellowknife. There is excellent agreement during the summer months important for weevil development. The shaded area represents the heat sum accumulation above 7.2°C.

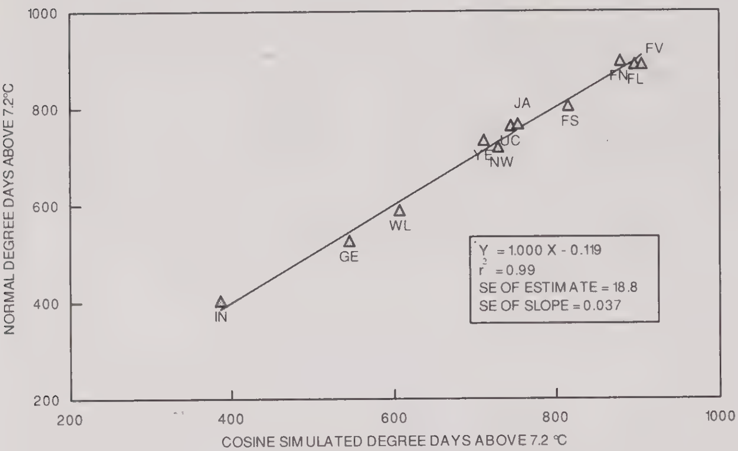

Figure 3. Comparison of heat sums (1951-1980 normals) calculated using measured and simulated daily temperatures for selected stations throughout the basin. IN=Inuvik, GE=Germansen Landing, WL=Watson Lake, NW= Norman Wells, YE=Yellowknife, UR=Uranium City, JA=Jasper, FS=Fort Simpson, FV=Fort Vermillion, FL=Fort Liard, FN=Fort Nelson.

(1993) may not have fully considered elevation in their interpolation process. Consequently, it was decided to adjust the monthly temperature data to properly reflect topography using the approach of Hallet and Jones (1993) and a geographic information system (GIS). Interpolation between climate stations is achieved by first bringing the climate station data to a common elevation such as sea level using a temperature lapse rate. Once at a common elevation, interpolation can be done to determine the temperature of points between the climate stations. The sea level temperatures are then adjusted to the true elevations using the lapse rate and a digital elevation model.

The Mackenzie Basin lapse rates are severely influenced by the presence of the arctic inversion (Reinhelt and Green, 1978). Due to the sparsity of high elevation Environment Canada climate stations in northern Canada, it is not possible to determine lapse rates using elevational sequences of climate stations. Thus, radiosonde[1] data were used to derive lapse rates for the basin. The radiosonde stations utilized for the study are presented in **Table 1**. The radiosonde station at Whitehorse Yukon was excluded from the analysis due to its proximity to the Pacific ocean, resulting in less influence of the arctic air mass than locations in the Mackenzie Basin.

Radiosonde data have been utilized previously to determine temperatures in areas with sparse climate stations. Burns (1973) used limited radiosonde data to construct maps of temperature in the Mackenzie Basin. Peterson (1969) utilized radiosonde data to describe the climate of mountainous areas in coastal British Columbia. Richner and Phillips (1984) investigated the difference between mean temperatures from mountain top climate stations and radiosonde data in Switzerland. They found that over a day the difference between mountain top climate stations and radiosonde observations was less than 1°C, and that this difference may be due to the accuracy of the instrumentation utilized. Luers and Eskridge (1995) state that the radiosonde sensors may overheat due to solar and infrared radiation but that the error is less than 0.5°C in the lower 15 km of the atmosphere, the biologically meaningful range for us. As lapse rates subtract the temperatures from two successive heights it is likely that any errors in temperature measurements would be present in both measurements and would cancel out in the subtraction, thus this error is of little concern for the determination of lapse rates.

Canadian radiosonde data were obtained from compact disks of compressed hourly North American radiosonde observations (United States National Climatic Data Center, 1995). Radiosonde stations take observations

Table 1: Location of Canadian and American Radiosonde stations utilized to derive lapse rates. Latitudes and longitudes are in decimal degrees.

Radiosonde Station Name	Code	Latitude (°N)	Longitude (°W)	Elevation (m)
Barter Island, Alaska	BTI	70.13	143.63	15
Coppermine, NWT	YCO	67.82	115.08	9
Edmonton Municipal Airport, Alberta	YXD	53.57	113.52	668
Fort Nelson, BC	YYE	58.83	122.58	379
Fort Smith, NWT	YSM	60.02	111.97	203
Inuvik, NWT	YEV	68.30	133.48	58
Norman Wells, NWT	YVQ	65.28	126.8	60
Prince George, BC	YXS	53.88	122.67	676
Sachs Harbour, NWT	YSY	71.98	125.28	84
Vernon, BC	YVR	50.23	119.28	556

worldwide at 0000 (5 pm Mountain Time) and 1200 (5 am Mountain Time) Greenwich time daily. These times roughly correspond to the times of daily maximums and minimums in the Mackenzie Basin. Environment Canada calculates daily average temperatures using the formula Daily Average = (Max + Min)/2. Using the radiosonde observations, lapse rates were determined as follows:

$$\text{Lapse rate from ht1 to ht2} = \text{temp 2} - \text{temp1} / (\text{height 2} - \text{height 1}) \qquad (2)$$

where temp is temperature at a specified height (°C), given by [(5 pm Mountain Time temperature + 5 am Mountain Time temperature)/2], and height (m) is the average height of the pressure level on a particular day.

Programs were written in Visual Basic (Microsoft, 1995) to process 1.6 Gigabytes of radiosonde data for stations in and around the Mackenzie Basin. SAS (SAS Institute, 1996) Statistical Programming Language was used to determine lapse rates by pressure level. Lapse rates were determined using 7 pressure levels (surface, 900, 850, 800, 750, 700 and 500 mb). To simplify calculations, the profiles were reduced to 3 layers (surface–850mb, 850mb–700mb, 700–500mb). Regional lapse rate regression equations were developed in SAS to adjust lapse rates on the basis of latitude. Lapse rates were applied to topographic elevational bands using the pressure to altitude conversion of the United States Committee on Extension to the Standard Atmosphere (Sissenswine, 1969). In the standard atmosphere, pressures of 850 mb, 700 mb and 500 mb correspond to altitudes of 1457 m, 3012 m, and 5574 m respectively.

The latitudinally varying lapse rates were utilized to bring the monthly 1951-1980 climate station mean temperature values (**Figure 4**) for western and northern Canada (Atmospheric Environment Service, 1982) and Alaska (National Climatic Data Center, 1982) down to sea level. Once at sea level SURFER (Golden Software, 1995) was utilized to interpolate a potential sea level temperature surface for each month. Each of these surfaces was imported to the IDRISI GIS. The sea level temperature of each of the MBIS grid points was queried in IDRISI and output to text files. The elevation of each of the MBIS grid points was also queried in IDRISI using the ETOPO5, topographic coverage with a resolution of five minutes of latitude and longitude (National Geophysical Data Center, 1988). Programs were written in SAS to bring the mean monthly temperature of each MBIS grid point up to its true (ETOPO5) elevation using the lapse rates derived above from radiosonde data.

Once elevationally corrected monthly temperatures had been determined for each of the MBIS grid points, SAS was used to determine daily leader temperatures using the cosine methodology previously discussed. SAS was utilized to calculate degree day heat sums from the cosine daily data using **Equation 1**. GISS climate change scenario data was applied utilizing the methodology of Smith and Cohen (1993) where regional offsets were added to the baseline 1951–1980 data (**Table 2**). Smith and Cohen (1993) provided offsets for three regions of the Mackenzie basin the northern Mackenzie (above 66.5 north latitude), the Mackenzie Valley (56 north latitude to 66.5 north latitude) and the southern Mackenzie (below 56 north latitude). May to September leader degree day totals for the MBIS grid points for 1951–1980 baseline period and the GISS 2050 scenario were imported into SURFER and maps of May–September degree day totals interpolated to cover the entire basin. These maps were imported into IDRISI and classified into high, medium, and low hazard classes as was described for the provided MBIS gridded tempera-

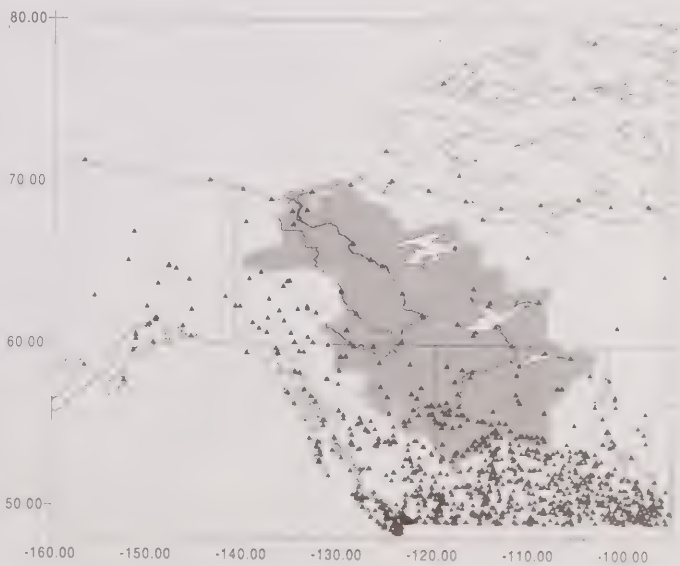

Figure 4. Location of the Environment Canada and American NOAA climate stations utilized to generate 1951-1980 monthly average temperature surfaces. The Mackenzie River Drainage Basin has been shaded.

ture data-set.

Results and Discussion:

It was not possible to utilize the same period for the climate station data (1951-1980) and radiosonde data. Canadian radiosonde data prior to 1957 are not in digital form and are not available for analysis. All radiosonde data post-1980 had to be discarded because it appears to contain numerous errors (**Figure 5**). Radiosonde data for Washington State and Alaska did not exhibit the problems seen in **Figure 5** in the Canadian data.

Radiosonde derived atmospheric temperature profiles by altitude and pressure level (surface and six levels) averaged for all available data from 1957–1980 are presented in **Figure 6** for January, April and July. October profiles are not presented as they are similar to April. The slope of the temperature profiles, the rate of change of temperature with elevation, or lapse rate, can be inferred from this graph. Positive slopes indicate an inversion while negative slopes indicate that temperature is decreasing with altitude in the atmosphere. In January, the strength of the arctic inversion increases moving northward.

To simplify calculations of the winter and spring lapse rates when inversions were observed, the seven levels presented in **Figure 6** were grouped into three layers (surface-850mb, 850mb-700mb, 700-

Table 2: GISS 2050 climate change scenario temperature offsets from the 1951–1980 baseline data for the Northern Mackenzie (>66.5°N), the Mackenzie Valley (56°N-66.5°N), and the Southern Mackenzie (<56°N). Source: Smith & Cohen (1993).

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northern Mackenzie	11.9	8.9	7.3	5.2	4.3	3.4	0.5	3.0	4.4	9.8	12.8	11.0
Mackenzie Valley	7.7	5.3	4.4	5.7	3.1	2.6	3.6	3.7	4.0	6.0	6.2	5.9
Southern Mackenzie	4.2	3.5	3.5	3.3	3.2	3.0	3.6	4.2	4.4	4.1	4.6	4.7

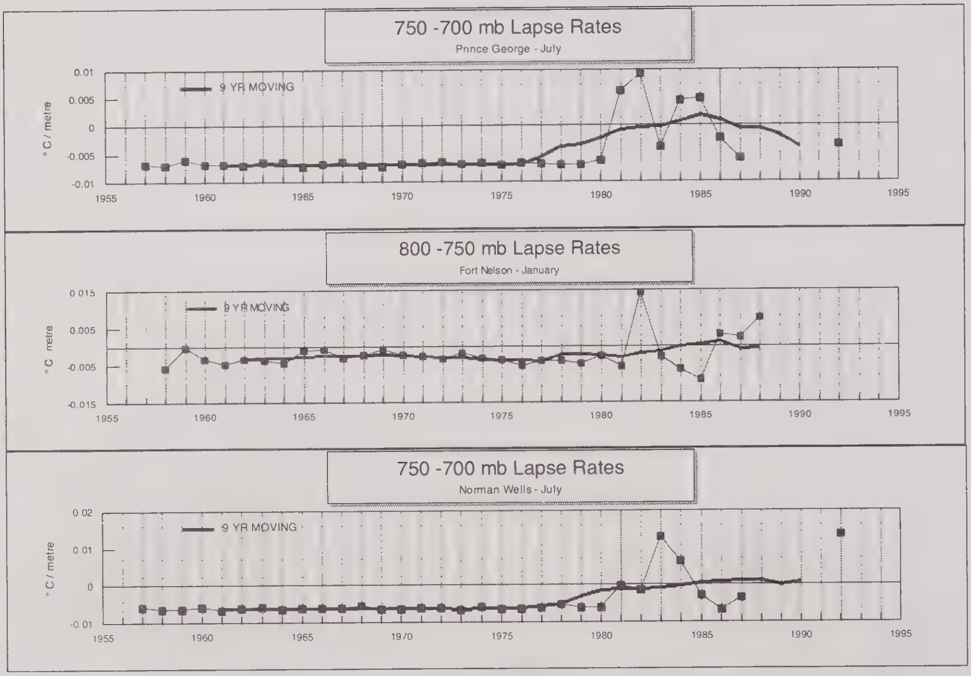

Figure 5. Many Canadian radiosonde stations exhibited data quality problems after 1980. Due to these data quality problems, only data up to and including 1980 was utilized to derive lapse rates for this study.

500mb). Above 3015 feet (700mb), there was little latitudinal or seasonal variation in the observed lapse rates with monthly lapse rates indicating a decrease of approximately 0.006°C per metre rise in altitude. In the 700–500 mb layer, lapse rates approached 0.006°C per metre in the summer, and in the winter were intermediate between the surface inversions and the 0.006°C per metre above resulting in near neutral lapse rate on average.

The surface to 850 mb layer (1457m) had the largest variation in lapse rates. In January, lapse rates varied from an increase in temperature of 0.008°C per metre rise in altitude in the northern basin to a decrease of 0.003°C per metre rise in altitude in the southern basin. In April, the inversion is still present at the northern extremes of the basin, while in the south it has broken up. In July there is little variation

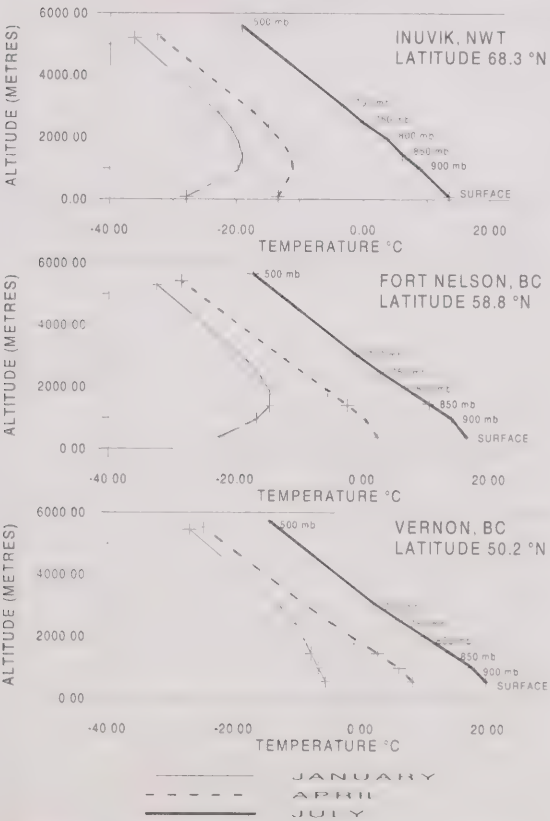

Figure 6. Radiosonde Derived atmospheric temperature profiles by altitude and pressure level demonstrate seasonal and latitudinal variation due to the strong arctic inversion.

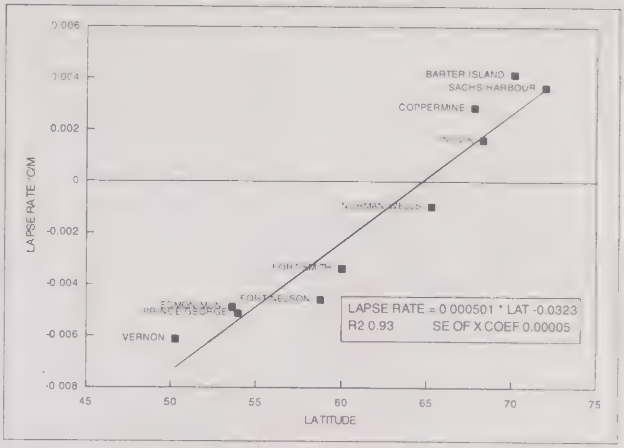

Figure 7. Latitudinal Variation in Lapse Rates For April for the surface to 850 mb (1457 m). Similar regression equations were developed for each month for and for each of the three pressure layers (surface–850mb, 850mb–700mb, 700–500mb).

of temperature with altitude or latitude with the July lapse rates indicating an approximate decrease of 0.006°C per metre rise in altitude.

Figure 7 indicates a typical regression equation utilized to adjust the lapse rate for variation due to latitude. In April for the surface to 1457m level, the arctic inversion is much stronger in the northern extremes of the basin, while in the southern portion of the basin, lapse rates show a decrease in temperature with elevation.

The 1951–1980 spruce weevil hazard produced using the non elevationally corrected MBIS temperature dataset (**Figure 8**) is quite different from the spruce weevil hazard map created using radiosonde lapse rates and the Hallet and Jones (1993) methodology (**Figure 9**). **Figure 8** does not appear to adequately represent the influence of elevation on temperature in the basin. We believe our approach better represents the true temperatures of the area considering the mountainous terrain. **Figure 8**, using the supplied MBIS temperature data does not depict the Rocky Mountains being colder than the surrounding terrain, while **Figure 9** using the radiosonde lapse rate approach depicts the Rocky Mountains as being cooler than the surrounding terrain.

Figure 10 depicts the weevil hazard using the 2050 GISS climate scenarios, the radiosonde lapse rates and the Hallet and Jones (1993) methodology. All of the area presently forested will be at risk from weevil damage. Thus all white spruce plantations planted in the area could poten-

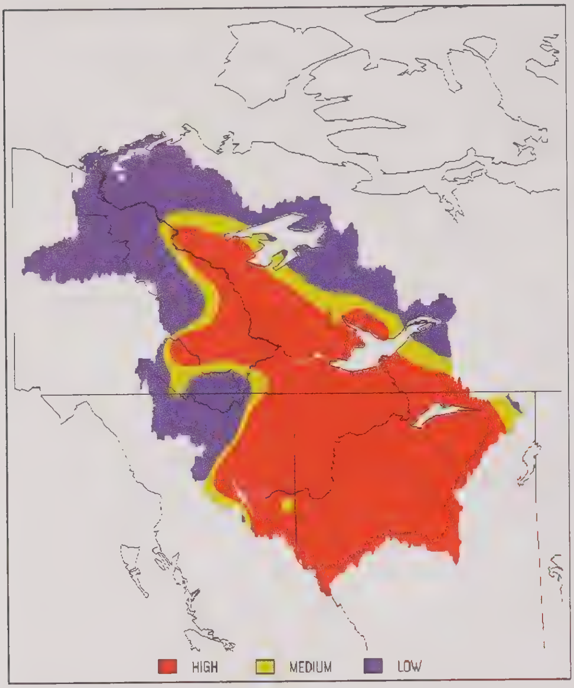

Figure 8. Weevil hazard in the Mackenzie Basin based on the 1951–80 temperature normals and produced in the IDRISI GIS package. The gridded MBIS temperature data (Smith and Cohen, 1993) did not adequately consider elevation in the interpolation process.

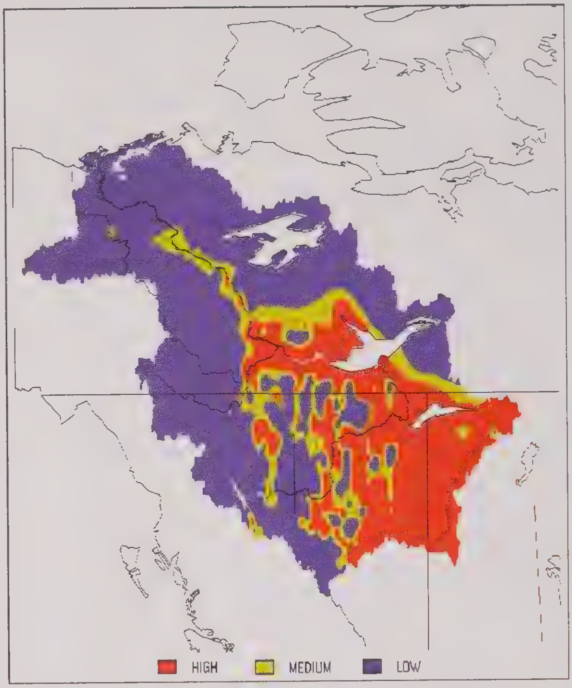

Figure 9. Weevil hazard in the Mackenzie Basin based on the 1951–80 temperature normals and produced in the IDRISI GIS package. Interpolated temperatures were adjusted for elevation using radiosonde derived lapse rates.

tially become susceptible to the weevil, leading to plantation failure and species other than white spruce becoming dominant. This hazard map indicates where it is warm enough for the weevil to complete its life cycle but does not consider such factors as the lack of a suitable host tree, overwinter mortality, predators or parasites.

The species composition and the structure of the boreal forest zone is predicted to change with climatic change. Hebda (1997) examined paleobotanical evidence in the boreal of northeast British Columbia in the warmer and drier Holocene and found that white spruce was more extensive than the present black spruce distribution. He utilizes this historical climate vegetation analogue to suggest that with a warmer and drier climate northeast British Columbia will largely become dominated by white spruce. Kadonaga (1997) suggests that the fire frequency and amount of area burned will increase with climatic warming in the Mackenzie Basin. Hartley and Marshall (1997) state that the increased fire frequency will result in younger forests due to the increased fire disturbance.

Because the spruce weevil is a pest of young regenerating forests, 5-40 year stand age (Alfaro, 1994), an increase in white spruce composition and a conversion to younger stands may create extensive habitat for the weevil. If the boreal becomes largely composed of stands of young white spruce all having sufficient heat sum for weevil development this may present large reforestation problems paralleling the problems in the central interior of British Columbia where there are now extensive plantations of spruce experiencing weevil damage (Alfaro, 1994).

Sufficient degree day heat sum and suitable host trees imply a high weevil damage risk if there is a source of weevil inoculation. McMullen and Condrashoff (1973) suggested that the insect has been found to fly less than 2 km per year in coastal British Columbia. McIntosh[2] indicates that weevil dispersal in the interior of British Columbia is largely through crawling and is limited to a few hundred metres. Alfaro (1994) suggests that this insect naturally has a 5% endemic population level in stands. Surveys have found the weevil up to the NWT and Alberta

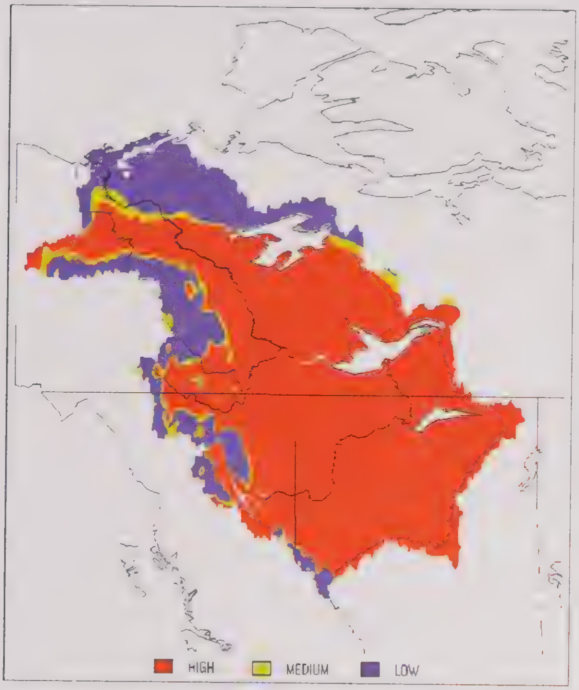

Figure 10. Weevil Hazard in the Mackenzie Basin based on the GISS 2050 temperature scenario and produced in the IDRISI GIS package. Interpolated temperatures were adjusted for elevation using radiosonde derived lapse rates.

border (Humble *et al.,* 1994). Because the weevil has at least endemic levels below 60°N latitude, it is likely that the insect will cause significant damage to stands in the southern portion of the basin with climate change. Damage in northern stands will depend on the time it takes for the insect to migrate northward to occupy its new potential range. Because the weevil is dependent on host trees for survival, weevil migration will likely be at a similar rate to the migration of host trees into new habitat.

It must not be forgotten that the spruce weevil is a herbivore that feeds on spruce. Climate change may change the nutritional content of the tree and hence the ability of the weevil to meet its nutritional demands. Changes in temperature and moisture may stress the tree, influencing the amount of nitrogen in the tissues (White, 1974; White 1984). Additionally an increase in CO_2 may result in the "nitrogen dilution effect" (Watt *et al.,* 1995) where plants fix more C relative to N uptake from the soil, changing the C/N ratio of the plant tissue and hence the nutritional value for insects. Increased CO_2 may also result in an increase in plant alleochemicals that are detrimental to insect development (Lindroth, 1996).

The interpolation of temperature could be further improved in the Mackenzie Basin through the use of more grid points than the 3800 (**Figure 1**) used by Smith and Cohen (1993). Smith and Cohen's grid points have been retained to maintain linkages with other MBIS studies and to allow access of our gridded MBIS elevationally corrected temperature data-set to other researchers. Cold air drainage has not been considered in this study. The influence of cold air drainage on temperature extrapolation to valley bottoms and spruce weevil hazard is presently being investigated by Sieben (1997) in the British Columbia portion of the Mackenzie Basin.

Three pressure levels were utilized in this study to adjust temperatures to simplify calculations. Sieben (1997) will repeat the approach utilized in this paper using lapse rates for the seven pressure levels available in the data-set (**Figure 6**). The regression equations that adjusted lapse rates using latitude could be further improved by incorporating variables such as the distance from the Pacific and Arctic Oceans.

This study utilized Spittlehouse *et al.* (1994) to assume leader temperatures would be 1°C warmer than air temperatures. Sieben (1997) will include a model to examine the spatial variation in the leader to air temperature offset under varying solar radiation loads and windspeeds.

Conclusions

The adjustment of the 1951–80 baseline MBIS temperature data-set using radiosonde derived lapse rates produced temperature coverages that consider the varied topography in the drainage basin. These data were used to determine the May to September degree day sums above a threshold of 7.2°C and to determine hazard for white pine leader weevil infestations of white spruce. Based on the 1951–1980 data, the southern half of the Mackenzie basin, excluding the Rocky Mountains, is in a medium or high hazard class. Considering climate warming alone, the weevil could expand its range northward in latitude and upward in elevation, to occupy all areas that presently contain white spruce.

Notes

1. Balloon-borne instrument that measures and transmits pressure, temperature and humidity to a ground based measuring station (Ahrens, 1991)
2. Personal Communication. Rory McIntosh, Ph.D. Candidate, University of British Columbia, Forest Science

Dept., Vancouver, BC

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6

WILDLIFE

Climate Warming and Marten, Lynx, and Red Fox in the Mackenzie Basin

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Abstract

The trapping of marten (Martes americana), lynx (Lynx canadensis), red fox (Vulpes vulpes) remains important to both the culture and local economies of many communities in the Mackenzie Basin. All three of these species depend on a mix of forest cover types within the boreal forest that overlies much of the Mackenzie Basin. Forest fire is the major agent responsible for creating this mosaic of forest cover types, removing the old, mature forest which is replaced by early seral stages having fundamentally different species composition, energy flow, and productivity. Climate warming models based on elevated levels of CO2 in the earth's atmosphere predict that over the next 50 years the mean annual temperature in the Mackenzie Basin may increase 3-5°C. With this increase in temperature, it has been predicted that the frequency and intensity of forest fire will increase substantially. In order to predict the effects of increased burn rate on wildlife, including furbearers, we need to know to the importance of different age burns to their ecology. At present there is little information on the use of various age burns in the boreal forest by important furbearers such as marten, lynx, and red fox. The present study was designed to examine the use in late winter of various age burns (1–21 yrs) by these three species in the mid-Mackenzie Valley. We assessed their presence in each burn by conducting track counts from a helicopter along randomly located transects. Within three of the four burns there was a significant decline in track counts for marten during the three years. Low track counts for lynx and red fox precluded statistical analysis, however there appeared to be a decline in these two also. In only one of the three years was there a significant difference in marten track counts among the four burns. Based solely on the results of this study and the few other similar studies conducted in the northern boreal forest, it is difficult to make predictions concerning populations of marten, lynx, and red fox in the Mackenzie Basin in a regime of more frequent and intense forest fire. However, we have attempted a 'best guess' for marten, lynx, and red fox given our present knowledge of the habitat requirments of these three species in the boreal forest.

Introduction

Forest wildfire and its suppression have long been a contentious issue in the Northwest Territories primarily because of the immediate effects it has on wildlife distribution and abundance, especially species of economic and cultural importance. Recently, predictions of rapid global warming over the next several decades due to the accumulation in the atmosphere of gases produced by combustion of hydrocarbons, has caused much speculation about consequences to the world's forests (e.g., Emanuel *et al.* 1985). In north-temperate and sub-arctic forests it has been predicted that fires will increase in frequency and that without greatly increased suppression efforts compared to the present day, the total amount of forest burned each season will rise dramatically (Kurz and Sampson 1991; Torn and Fried 1992). At present, we have little information on the effects of wildfire on wildlife in the northern boreal forest (taiga) found over much of the western Northwest Territories. We, therefore, have no basis for making even the most general of predictions as to what can be expected in a given burn any number of years afterwards. It follows that we are completely ill-equipped to make even the most fundamental predictions concerning the effects of a rapidly accelerated fire frequency regime. This predictive capability is important in order that communities and government can better know, and plan for, the impacts of fire in the future.

The Department of Renewable Resources initiated a study of the recovery of wildlife in forest burns in the Sahtu District in particular furbearers and ungulates. Initially, this study was designed to serve Department interests and concerns surrounding fire management in the NWT and its implications to wildlife. Then, in 1990 the Mackenzie Basin Impact Study (MBIS) was established to examine the potential impacts of future climate change on the Mackenzie Basin. It was apparent that findings of the initial study might be applicable to the broader considerations of the MBIS especially the hypothesized greater fire frequency in the boreal forest because of global warming. The objectives of this study were:

1) to determine the relative abundances of marten, lynx and red fox in burns of different ages in the Sahtu District of the Mackenzie Basin;

2) to describe the vegetation characteristics of the above burns.

Methods

Burn selection

Four burns were selected in 1990 (**Figure 1**) by examining detailed maps of the last 20 years of fire history prepared by the Territorial Fire Centre. We attempted to select burns that represented a range of ages from 1–21 yrs and were >80 km^2. The following burns were selected: Fort Norman–1989 (318 km^2), Chick Lake–1987 (88 km^2), Fort Good Hope–1976 (488 km^2), Norman Wells–1969 (129 km^2).

Track counts

Direct methods such as counts of individuals are not applicable for assessing the abundance of medium size carnivores in forested habitat. Indirect methods such as live capture were not practical in the Sahtu District because of the vastness of the area and time/budget constraints. Quantifying track sign in the snow remained the only viable technique for assessing the abundance of furbearers within burns in the Sahtu District, at least during mid to late winter. However, the complete lack of ground access to old burns that are distributed over a such large area, plus the difficult mobility within these burns in winter, negated the possibility of ground-based track counts. Therefore, we conducted aerial counts of marten, lynx, and red fox tracks. Counts of the three species' tracks were made along randomly located, 2 km transects situated in 4 burns. Counts were made from a Bell 206B helicopter flying at 15 m agl. and 30-35 km/hr. Each burn had 1 transect/ 5-10 km^2; the larger burns had a lower transect density than did the smaller burns.

The track observation rate (TOR) for each species along a transect was converted to a corrected TOR (CTOR) as follows,

$$CTOR = TOR*1.5/DAS$$

where 1.5 is a sightability correction factor derived by Golden (1987) for aerial counts of carnivore tracks and DAS is the number of days after snowfall that the count was conducted. Division by DAS standardizes the track counts from different burns regardless of when after a snowfall the count was done in each burn. This assumes that there is a near linear accumulation rate of tracks after the last snowfall, as found by Golden (1987). The analysis here used both CTOR and TOR data.

Burn description

Landsat TM data was acquired for each of the 4 burns. This data was already available at the NWT Centre for Remote Sensing (NWTCRS), Yellowknife and consisted of 7-band computer compatible tapes. Analysis of the digital imagery was performed on an ARIES III image analysis system at the NWTCRS.

Enhancements of the digital imagery for each burn were produced using stretch, power, exponential, and histogram equalization techniques. These enhancements were then initially truthed by means of aerial assessment of landform, topography, aspect, slope, moisture level, substrate type, canopy type and density, shrub type and density, and ground cover from a Bell 206B helicopter 30-50 m above the ground (see **Appendix I**). The statistical discreteness of the spectral classes was then tested using discriminant function analysis of this descriptive data. In this way the initial classification was verified or rejected. If rejected, the enhancement would be reclassified into fewer or additional spectral classes.

After reclassification, we ground truthed the enhancement of each burn using 20 x 20 m plots lo-

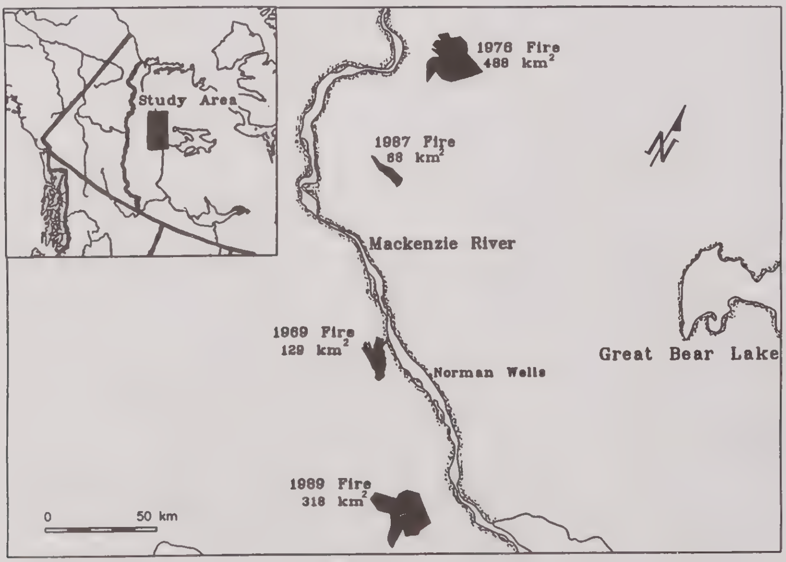

Figure 1. Locations of the Fort Norman-1989, Chick Lake-1987, Fort Good Hope-1976, Norman Wells-1969 burns.

cated at 200 m intervals along transects (**Appendix II**) within each vegetation association (i.e., spectral band or distinct color). A minimum of 10 plots were located in each vegetation association. Within a plot, 5 quadrats (1 x 1 m) were randomly placed and the coverage of all species of grass, herbs, and shrubs within each was estimated. A count of snags >1.5 m in height was obtained from a 1 m wide strip across the middle of the plot; the diameter at breast height for 10 randomly selected snags within the strip was measured. The coverage of deadfall was estimated for the entire plot. The horizontal density of shrubs was assessed by holding a .5 x .5 m white board at chest height 60 m from an observer at the centre of the plot. The observer recorded the amount (%) of board visible; this was repeated 10 times around the plot (see **Appendix III**).

After the vegetational characteristics were determined by ground truthing, two techniques were used to verify the classified image for a particular burn. Firstly, a comparison matrix was used to determine the agreement between the vegetational classification of each 20 x 20 m plot prior to, and after, ground truthing. Secondly, the vegetational classification of an entire burn was tested statistically by pooling all plots occurring within the same vegetation type and comparing these with the pooled plots from each of the other vegetation types for that particular burn.

Results

Track counts

Aerial track counts were conducted over three years (1991-93). There was considerable variability between transects in the track counts for marten, lynx, and fox (combined 1991 and 1992 data only; **Figures 2–4**). Marten tracks were observed on 87% of all transects in the 4 burns (**Figure 2**). The majority (65%) of transects had CTOR's of .3-1.5 tracks/2 km and the maximum CTOR count was 2.5 tracks/2 km (**Figure 2**). These CTOR's correspond to a TOR of .6-4.4 tracks/2 km and a maximum TOR of 7.3 tracks/2 km. These TOR's indicate the actual number of tracks that could be expected along the 2 km transects in the 4 burns if surveys were done between 2.5 and 8 days after snowfall (DAS). A much greater percentage of the 2 km transects had zero lynx (64%) and red fox track (54%) counts (**Figures 3 and 4**) compared to marten (13%).

In 3 of the 4 burns, there was a significant decline during the 3 years in the corrected track counts for marten (**Table 1**) along the transects within each burn (Fort Norman, F = 5.15, P = .01; Chick Lake, F = 7.79, P = .002;

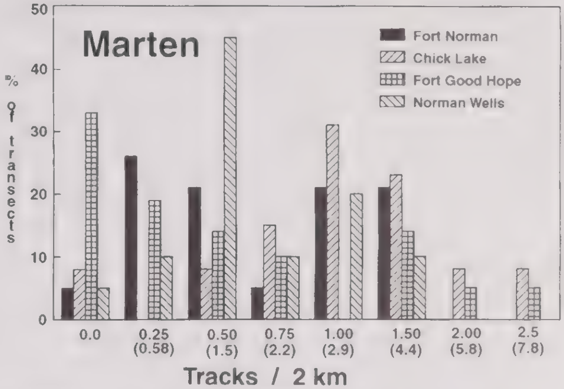

Figure 2. Frequency distribution of CTOR's and TOR's (in brackets) for marten along the 2 km transects in each of the 4 burns.

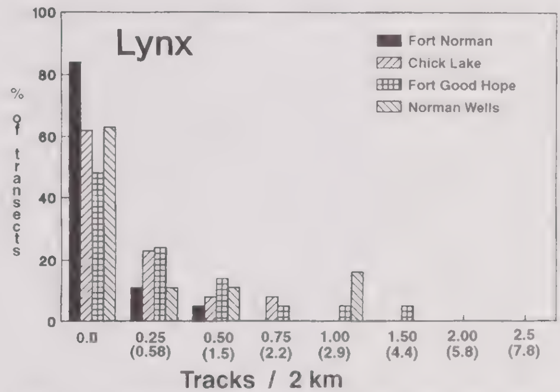

Figure 3. Frequency distribution of CTOR's and TOR's (in brackets) for lynx along the 2 km transects in each of the 4 burns.

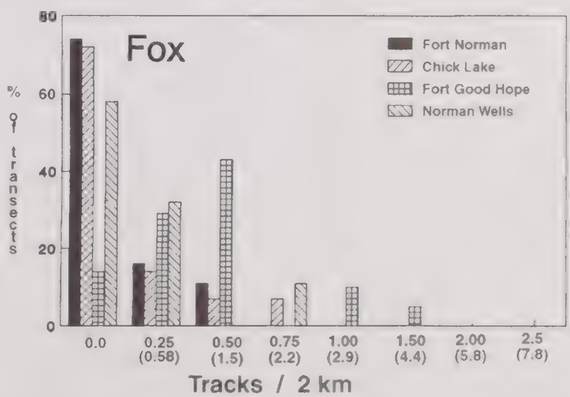

Figure 4. Frequency distribution of CTOR's and TOR's (in brackets) for red fox along the 2 km transects in each of the 4 burns.

Norman Wells, F = 6.73, P = .003). The remaining burn (Fort Good Hope-1976) showed no significant difference during the 3 years (F = 0.84, P = 0.44). The 4 burns were, therefore, compared for each year separately. Only in 1991 did the 4 burns differ significantly in the corrected track counts for marten along the transects within each burn (F = 17.04, P = .0001). In 1992 and 1993, there was no significant difference among the 4 burns (F = 1.95 and 2.01, P = .13 and .12 respectively). The corrected track counts for red fox and lynx also appeared to decline during the 3 years (**Tables 2 and 3**). However, the large number of zero counts along the transects for both lynx and red fox made statistical comparison impossible. All three species were present in the youngest burn (Fort Norman - 1989).

Burn description

Aerial assessment of satellite imagery for the 4 burns was conducted in 1991. A detailed description of the results is not presented here but, in general, there was close agreement between the classifications and the aerial assessment of each burn.

The plant species composition and coverage was quantified in each of the 4 burns. Appendices 4-7 indicate the species recorded in each burn, the mean coverage for each species, and the number of times it was recorded in the 1 x 1 m quadrats.

Table 1. Track observation rates (TOR) and corrected track observation rates (CTOR) for marten in 1991 and 1992 in the four burns.

Track observation rate (TOR) in each burn (tr./2 km)

	Fort Norman 1989	Chick Lake 1987	Fort Good Hope 1976	Norman Wells 1969
1991	4.2	3.1	0.3	2.3
1992	1.7	2.0	1.1	1.5
1993	0.9	1.7	0.6	1.2

Corrected track observation rate (CTOR) in each burn (tr./2 km)

	Fort Norman 1989	Chick Lake 1987	Fort Good Hope 1976	Norman Wells 1969
1991	0.8	1.5	0.2	0.5
1992	0.6	0.7	0.4	0.8
1993	0.2	0.6	0.3	0.3

F = 2.18, P = .09

*CTOR = TOR*1.5/DAS

where: - 1.5 is the observer error correction factor (after Golden, NPS)
- DAS is days after snowfall

Table 2. Track observation rates (TOR) and corrected track observation rates (CTOR) for lynx in 1991 and 1992 in the four burns.

Track observation rate (TOR) in each burn (tr./2 km)

	Fort Norman 1989	Chick Lake 1987	Fort Good Hope 1976	Norman Wells 1969
1991	0.30	0.60	0.50	1.30
1992	0.10	0.00	0.40	0.10
1993	0.10	0.10	0.20	0.10

Corrected track observation rate (CTOR) in each burn (tr./2 km)

	Fort Norman 1989	Chick Lake 1987	Fort Good Hope 1976	Norman Wells 1969
1991	0.10	0.30	0.10	0.30
1992	0.10	0.00	0.10	0.20
1993	0.03	0.02	0.10	0.01

Discussion

Climate models based on 2 X CO_2 levels suggest that mean annual temperature will rise 3-5° C by the mid-21st century. This would likely have great significance for the closed boreal and taiga (open boreal) forests of the Mackenzie Basin. For example, greater evapo-transpiration during the fire period of May-September would exacerbate the factors that directly influence wildfire in the northern forests, mainly the moisture content of soil, duff, herbaceous, and woody fuels. Kadonaga (1996), using two models of global warming, predicted that the Fire Weather Index (FWI), a measure of fire threat at any given time based on several daily weather indices, would increase the early season (May) fire danger across a broad area of the Mackenzie Basin. In addition, there would be fire danger increases over portions of the basin during the June-July period, historically the time of greatest fire occurrence in the Mackenzie Basin. Indeed, there is some suggestion that such a trend may already be unfolding. The 1980s and early 1990s saw dramatic increases in the amount of northern forest burned (Wein *et al.,* 1994) with record amounts occurring in 1994 and again in 1995 (R. Lanoville, pers. comm.). Various authors have predicted that a warming of climate over the next 50 years could result in substantial increases to the amount of area burned annually in the boreal forest, per-

Table 3. Track observation rates (TOR) and corrected track observation rates (CTOR) for red fox in 1991 and 1992 in the four burns.

Track observation rate (TOR) in each burn (tr./2 km)

	Fort Norman 1989	Chick Lake 1987	Fort Good Hope 1976	Norman Wells 1969
1991	0.50	0.30	0.60	1.70
1992	0.30	0.10	1.00	0.00
1993	0.03	0.03	0.70	0.00

Corrected track observation rate (CTOR) in each burn (tr./2 km)

	Fort Norman 1989	Chick Lake 1987	Fort Good Hope 1976	Norman Wells 1969
1991	0.10	0.10	0.40	0.40
1992	0.10	0.10	0.40	0.00
1993	0.01	0.01	0.30	0.00

haps by as much as 50% (Flannigan and van Wagner, 1990).

Predictions of increased amounts of boreal forest consumed by wildfire on an annual basis due to climate warming assume wildfire suppression efforts will remain at present day levels. It is impossible to predict whether this will be the case. It is possible that societal desires and political pressure could result in heightened fire suppression efforts in order to protect local economies dependent on the harvest of renewable resources. For the purpose of this discussion, however, it is assumed that the number of forest fires started will equal, and in some years greatly exceed, that witnessed during the worst fire seasons in the 1990s, and that suppression effort will be similar to the present. Under these circumstances we can expect considerably greater area burned each fire season than is presently the case.

Marten

Marten over most of North America prefer mature forest although habitat selection may be more diverse than the strictly old-growth conifer selection orginally ascribed to the species (Seton, 1929; Buskirk and Powell, 1994). Various studies conducted in the boreal forest (Magoun and Vernam, 1986; Latour *et al.,* 1994; Thompson, 1994; Thompson and Colgan, 1994; Johnson *et al.,* 1995; this study) have shown that marten will use large openings created in the forest by either fire or logging, but they do not use them intensively (Latour *et al.,* 1994; Johnson *et al.,* 1995). In the Mackenzie Valley, use of burned areas occurred in both summer and in winter (Latour *et al.,* 1994; this study) when snow pack, particularly in late winter, covered much of the fallen timber which marten use to access sub-nivean space for hunting small mammals (Corn and Raphael, 1992; Johnson *et al.,* 1995). Stephenson (1984) reported numerous trappers in Alaska who observed marten in burns within 1-3 years post-fire with higher densities of marten in some burns 6-15 years old compared to the surrounding unburned forest. In this study, we did not detect any difference in use by marten of four different age burns in the Mackenzie Valley. It is likely that recent openings in the mature forest created by fire or logging are mainly sinks of suboptimal habitat for dispersing juveniles (Johnson *et al.,* 1995) which are generally less selective in their habitat preferences (Buskirk and Powell, 1994). Survival rates of marten that used exclusively logged areas in the boreal forest of northern Ontario were markedly lower than marten using exclusively mature forest (Thompson, 1994). The value to marten of burned areas in the boreal forest is determined largely by the abundance and availability of small mammals, primarily Microtus spp., Clethrionymys sp., and snowshoe hare (Lepus americanus) (Douglass *et al.,* 1983; Johnson *et al.,* 1995; Poole and Graf, 1996). It appears abundance and availability of small mammals is determined largely by the age of the burn and its regeneration pattern which, in turn, is affected by a number of factors including the intensity of the original burn. (Fox, 1983; Johnson *et al.,* 1995). With a warmer climate, it is predicted that more forest fires in the boreal forest will burn at a higher intensity than is presently the case. Intensive burns tend to regenerate differently than light and moderate burns (Viereck, 1983). How small mammal populations respond to greater amounts of this regeneration type could have a major affect on marten populations over large areas, particularly as increasing amounts of area are intensively burned in the future.

Another consideration is the possible effects that climate warming might have on the optimal habitat of marten, namely forest that escapes fire over a prolonged period (50-80 years). It has been predicted that species composition and growth rate of this forest could change substantially (Bonan *et al.,* 1990; Kurz and Simpson, 1991; Hartley, I. and P. Marshall, 1996) under warmer growing conditions. Such changes could affect the species diversity and abundance of small mammals, the martens' ability to exploit small mammal prey, and other factors important in the ecology of marten (e.g., resting locations) (Buskirk and Powell, 1994). Climate warming may also result in the treeline shifting northwards (Payette *et al.,* 1989; Wein *et al.,* 1994) which could con-

ceivably create additional habitat for marten in the Mackenzie Basin. However, the rate at which treeline advance would occur and whether there would be significant change over 50 years is unclear (Sirois and Payette, 1991).

It appears that on a broad scale, increasing amounts of recently and intensively burned forest in the Mackenzie Basin over the next 50 years, would have at best a neutral effect on the densities of marten and perhaps a negative effect. At a more local level, say within the traditional trapping area of a community in the Mackenzie Valley, marten densities would be dependent on the mix of unburned forest (> 80 years old) and various ages of burned forest. The importance to marten of various stages and types of regenerating closed boreal and taiga forests, as measured by the long-term survival and reproductive success of marten residing permanently within these stages, needs further study. Only after that, could we make confident predictions concerning climate warming and its effects on marten populations, at both the local and regional level.

Lynx

Lynx prefer mature conifer-dominated forest mixed with earlier seral stages, the kind created naturally by forest fire (Quinn and Parker, 1987; Poole *et al.,* 1996). These early seral stages, consisting of primarily deciduous shrubs and densely regenerating conifers, tend to support the highest densities of snowshoe hare, the major prey of lynx (Quinn and Parker, 1987; Poole *et al.,* 1996). Stands of mature forest appear to be important for denning as well as supplying alternative prey when snowshoe hare numbers are low (Staples, 1995:cited in Johnson *et al.,* 1995). Lynx population dynamics are closely tied to the 10 year cycle of the snowshoe hare. When hare numbers are high, lynx reproduction is high, as are lynx densities (Brand and Keith, 1979). When hare numbers are low lynx recruitment is low, sometimes ceasing altogether, adult mortality rate increases, and surviving adults expand their home ranges greatly or move long distances away from their natal area (Poole, 1994). Thus, in predicting the effects of climate warming and a resulting increase in the amount of burned area and intensity of burning in the boreal forest on a prey dependent species such as lynx, it is imperative to understand snowshoe hare responses to these factors.

Based on our current understanding of snowshoe hare habitat preferences, at least in the southern boreal forest (Keith, 1990), more burned forest in the Mackenzie Basin would likely result in more habitat created for snowshoe hares. It is more difficult to conclude the same for the more northern, taiga forest of the Mackenzie Basin, since our knowledge of snowshoe hare populations in that forest type is poor. Lack of information on regeneration patterns in a warmer climate and possible changes in the structure of mature, unburned forest also confound predictions concerning lynx, as with marten. In that fire has the capacity to increase the amount of good snowshoe hare habitat, especially habitat that could serve as refugia for hares during the low in their cycle (Poole 1994; Perham, 1995: cited in Johnson *et al.,* 1995), over the long-term, fire might have a positive affect on lynx populations. Given that lynx appear to favour a mix of forest types, what may be important is the ratio of burned to unburned forest and the mosaic of these vegetation types (i.e., patches versus large areas) over the next 50 years. Without being able to accurately predict what this ratio might be, it is difficult to make predictions over a broad scale (i.e., the Mackenzie Basin). In this study, we found that lynx occurred in four different age burns in the Mackenzie Valley with the highest track counts in the two oldest burns. However, these surveys were conducted during 1991-93 when snowshore hare numbers were low and decreasing in the Mackenzie Valley, as were lynx numbers (lynx harvest returns, K. Poole, pers. comm.). In terms of community relevance in the Mackenzie Basin, how these factors interrelate within the communities' respective traditional trapping areas will determine whether lynx numbers could support economically viable trapping in a particular community. It may very well be that some areas escape burning in excess of what is optimal for lynx either by chance or through factors such as local weather or watertable characteristics, and could remain as refugia for resident lynx from which juveniles disperse into surrounding, less favourable areas. As with other furbearers, we need more information on the importance to lynx of various stages and types of regeneration in the closed boreal and taiga forests, as well as changes to the remaining unburned forest due to climate warming. Only then could we make more confident predictions concerning climate warming and it affects on lynx populations, at both the local and regional level.

Red fox

Red fox, in contrast to marten and lynx, are habitat generalists across their broad North American, European, and Asian range (Voigt, 1987). Red fox are more opportunistic in diet than marten and lynx and take a variety of prey and other items (e.g., carrion). This means that the numbers and distribution of red fox in the boreal forest are less dependent on vegetation characteristics per se than marten and lynx. There remains, however, a paucity of data

on red fox ecology in the boreal forest. Presumeably, most red fox prey consists of small mammals including microtines and snowshoe hares which they could obtain in burns, as do marten and lynx. In addition, red fox can probably exploit a variety of prey associated with mature forest, such as red squirrels *(Tamiasciurus hudsonicus)* and a variety of birds. Trappers in Alaska reported red fox using recent burns and that red fox responded to fire similarly to marten (Stephenson, 1984). In the present study, red fox occurred in all four burns and track counts were highest in the two oldest burns.

As with marten and lynx, the response of red fox populations to increasing amounts of burned boreal forest in the Mackenzie Basin will depend on a variety of factors of which we still have little knowledge. Regeneration characteristics under warmer conditions and after more intensive burning, forest structure under warmer growing conditions, and the particular mosaic of burned to unburned forest during the next 50 years will all influence red fox numbers and distribution in the Mackenzie Basin. In that red fox are flexible in their habitat use and given their ability to exploit a variety of prey including snowshoe hares which respond positively to fire, greater amounts of burned area in the Mackenzie Basin might affect red fox populations positively. More study is required before we can make predictions concerning climate warming and its effects on red fox, at both the local and regional level.

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Appendix 1

Plant species recorded in the Fort Norman-1989 burn, the number of quadrats it was recorded in and the mean coverage along with associated standard deviation and coeffecient of variation. N equals number of 20 x 20 m plots a species was observed in out of 30 plots.

	N	Mean coverage per plot	S.D.	C.V.
Trees and shrubs				
Alnus sp.	2	0.5	0.1	28.3
Arctostaphylos rubra	9	2.2	2.7	127.1
Betula spp.	12	2.3	2.6	117.4
Empetrum nigrum	2	1.9	0.1	7.4
Ledum palustre	29	2.7	2.0	75.3
Picea spp.	9	1.3	2.2	168.8
Populus tremuloides	1	0.6	—	—
Potentilla fruticosa	3	1.1	0.6	60.3
Rhododendron lapp.	2	0.4	—	—
Rosa acicularis	14	0.8	0.7	76.9
Rubus chamaemorus	25	1.4	1.3	91.8
Salix spp.	20	1.9	2.2	113.8
Vaccinium uliginosum	12	1.6	1.8	80.6
Vaccinium vitis-idaea	11	0.8	0.6	80.5
Vaccinium sp.	15	1.9	1.8	91.2
Sedges and grasses				
Carex spp.	12	0.9	1.4	159.3
Gramineae	25	1.5	1.4	90.3
Forbs				
Anemone parviflora	4	0.4	0.1	28.6
Cornus canadensis	1	0.6	—	—
Epilobium angusti.	12	3.2	3.9	122.8
Equisetum spp.	26	4.4	5.7	129.0
Platanthera obtusata	3	0.2	—	—
Parnassia palustris	1	0.2	—	—

Pedicularis sp.	1	0.2	——	——
Petasites sagittatus	1	1.8	——	——
Polygonum sp.	1	0.8	——	——
Pyrola secunda	6	0.5	0.3	65.7
Ranunculus sp.	3	0.6	0.4	66.8
Rumex sp.	3	0.3	0.1	43.3
Senecio sp.	7	0.6	0.3	42.8
Lichens	11	2.2	3.5	140.8
Moss 27	14.4	14.1	——	98.1
Litter/bare ground	30	73.5	19.9	27.1

Appendix 2

Plant species recorded in the Chick Lake-1987 burn, the number of quadrats it was recorded in and the mean coverage along with associated standard error and coefficient of variation. N equals number of 20 x 20 m plots a species was observed in out of 33 plots.

	N	Mean coverage per plot	S.D.	C.V.
Trees and shrubs				
Alnus sp.	22	4.0	4.7	118.2
Arctostaphylos rubra	27	5.5	2.9	53.5
Betula spp.	19	3.0	2.8	90.6
Chamaedaphne calycul.	1	1.2	——	——
Ledum palustre	24	2.7	2.2	80.9
Linnaea borealis	9	1.1	1.9	167.2
Picea spp.	30	0.7	0.4	53.6
Populus tremuloides	3	0.3	0.2	69.3
Potentilla fruticosa	24	3.2	3.7	116.5
Ribes lacustre	13	0.3	0.2	62.8
Rosa acicularis	21	1.6	1.7	103.7
Rubus chamaemorus	9	0.8	0.6	70.9
Salix spp.	33	8.1	4.2	52.1
Shepherdia canadensis	6	1.1	0.6	55.2
Vaccinium sp.	31	1.6	2.4	150.2
Sedges and grasses				
Carex sp.	30	4.5	4.9	106.9
Gramineae	25	2.4	2.8	113.5
Forbs				
Anemone parviflora	6	0.5	0.4	84.3
Cornus canadensis	2	4.1	3.8	93.1
Dryas integrifolia	2	0.7	0.4	60.6
Epilobium angusti.	39	4.1	4.5	110.9
Equisetum spp.	48	4.4	5.4	122.2
Galium boreale	3	0.5	0.1	21.6
Gentiana amarella	1	0.4	——	——
Geocaulon lividum	1	0.4	——	——
Platanthera obtusata	2	1.1	0.7	64.3
Pyrola secunda	16	0.5	0.7	132.2
Ranunculus sp.	6	1.0	0.4	44.2
Senecio sp.	6	0.5	0.4	79.0
Solidago sp.	3	0.4	0.2	50.0
Viola renifolia	2	0.2	——	——
Unknown forbs	10	0.7	0.5	70.8
Lichens	13	5.3	7.0	131.5
Moss 33	29.2	15.6		53.7
Litter/bare ground	33	47.1	14.5	30.7

Appendix 3

Plant species recorded in the Fort Good Hope-1976 burn, the number of quadrats it was recorded in and the mean coverage along with associated standard error and coefficient of variation. N equals number of 20 x 20 m plots a species was observed in out of 46 plots.

	N	Mean coverage per plot	S.D.	C.V.
Trees and shrubs				
Alnus sp.	9	6.8	7.8	115.5
Arctostphylos rubra	35	5.3	4.6	86.8
Betula spp.	29	7.1	7.6	107.0
Empetrum nigrum	1	0.6	——	——
Juniperus sp.	1	0.2	——	——
Larix laricina	6	0.5	0.4	65.7
Ledum palustre	26	1.5	1.8	120.8
Linnaea borealis	11	0.6	0.5	74.5
Picea spp.	41	3.1	4.1	134.5
Populus tremuloides	6	0.4	0.2	41.1
Potentilla fruticosa	30	2.2	2.5	112.5
Rhododendron lapp.	1	0.2	——	——
Ribes sp.	2	0.2	——	——
Rosa acicularis	7	0.9	0.5	62.8
Rubus chamaemorus	8	1.1	0.8	73.0
Salix spp.	44	10.2	7.0	68.5
Shepherdia canadensis	20	3.0	5.1	169.9
Larix laricina	1	0.6	——	——
Vaccinium uliginosum	10	2.1	2.5	118.2
Vaccinium vitis-idaea	16	4.7	4.2	89.8
Vaccinium sp.	11	0.9	0.9	98.9
Sedges and grasses				
Carex spp.	3.8	9.1		238.0
Gramineae	17	5.5	8.7	159.0

Forbs				
Arnica sp.	1	0.2	—	—
Aster sp.	7	0.3	0.1	38.0
Astragalus sp.	2	0.6	0.3	47.1
Cerastium arvense	1	0.2	—	—
Cornus canadensis	1	1.4	—	—
Dryas integrifolia	18	3.0	3.7	122.4
Epilobium angusti.	34	1.0	0.6	63.5
Equisetum spp.	40	5.2	7.5	145.6
Erigeron sp.	3	0.2	—	—
Galium boreale	6	0.4	0.3	77.5
Gentiana amarella	5	0.3	0.2	55.9
Geocaulon lividum	2	0.3	0.1	47.1
Hedysarum sp.	7	1.1	1.8	157.8
Oxytropis sp.	2	0.3	0.1	47.1
Parnassia palustris	3	0.3	0.1	43.3
Petasites sagittatus	2	1.8	1.7	94.3
Pyrola secunda	15	0.8	0.8	100.6
Ranunculus sp.	12	0.6	0.7	125.3
Rumex sp.	2	0.3	0.1	47.1
Senecio sp.	9	0.4	0.3	54.1
Zygadenus elegans	1	0.2	—	—
Lichens	26	6.2	14.8	238.4
Moss 34	12.1	12.6		104.3
Litter/bare ground	45	54.7	23.4	42.7

Appendix 4

Plants species recorded in the Norman Wells-1969 burn, the number of quadrats it was recorded in and the mean coverage along with associated standard error and coefficient of variation. N equals number of 20 x 20 m plots a species was observed in out of 27 plots.

	N	Mean coverage per plot	S.D.	C.V.
Trees and shrubs				
Alnus sp.	15	5.7	5.4	95.5
Arctostaphylos rubra	1	3.6	—	—
Betula spp.	13	2.6	3.3	127.4
Empetrum nigrum	2	2.5	0.1	5.7
Ledum palustre	23	14.5	8.3	57.4
Picea spp.	27	8.7	10.3	117.9
Ribes sp.	6	0.6	0.3	46.5
Rosa acicularis	15	1.7	1.8	109.3
Rubus chamaemorus	12	2.9	2.1	71.8
Salix spp.	16	7.0	5.0	70.6
Vaccinium sp.	27	7.9	6.8	86.1
Sedges and grasses				
Carex spp.	3	1.9	1.9	99.4
Gramineae	13	1.0	1.1	120.9
Forbs				
Cornus canadensis	16	9.7	13.7	140.8
Epilobium angusti.	10	0.8	0.5	62.7
Equisetum spp.	18	1.3	0.7	53.5
Platanthera obtusata	1	0.4	—	—
Unknown forbs	9	1.4	2.6	185.0
Lichens	13	0.9	0.8	84.1
Moss 27	50.7	24.1		47.5
Litter/bare ground	27	38.2	19.6	51.3

Climate change and yield considerations for cold-water fish based on measures of thermal habitat: Lake trout in The MacKenzie Great Lakes

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Introduction

"Many hours can be spent listening to an old-timer like Alex Augier, who can recall the events of 40 or 50 years ago as if they happened yesterday...; of trout so thick that (with few nets they) would fill the fish bins..."

Smith, 1981

While Odysseus slept, his crew opened the potent purse, releasing unfavourable winds because they did not know the special invocations. The winds still blow unfettered to this day.

after Homer, circa 850? B.C.

The conditions in great lakes can be thought of as 'state-of-the environment' indicators for the planet as a whole, by virtue of their responses to global, as well as more regional, phenomena (e.g., Gorrie, 1991). The influences of great lakes are also far-reaching; they can, for example, control mesoscale climates (Hutchinson, 1957). The MacKenzie basin is highly unusual in that it contains three such lakes: Athabasca, Great Slave, and Great Bear, arrayed equidistantly along a SE-NW latitudinal gradient extending to the Arctic Circle (**Figure 1**). They are perhaps the most striking features of the basin landscape, super reservoirs of freshwater, collecting much of the surface water in the basin before it flows into the Arctic Ocean. Paradoxically, we know little about the MacKenzie great lake ecosystems.

Much of what we know about the MacKenzie great lake ecosystems was obtained in the decade following World War II, a period which coincided with the development of a commercial lake trout-lake whitefish fishery on Great Slave Lake (e.g., Rawson, 1947*a*). Rawson (1950, 1951, 1953, 1956) surveyed most of the major components of the Great Slave Lake ecosystem in some detail, including physical-chemical characteristics, the plankton, and benthos as well as the fish, through the initial years of the fishery. Kennedy (1953*a*, 1954, 1956) monitored the fishery. Additional work was undertaken on Lakes Athabasca (Larkin, 1946, 1948) and Great Bear (Miller, 1946; Miller and Kennedy, 1948*a*, 1948*b*; Kennedy, 1949, 1953*b*) but for the most part the work was on isolated components hence narrow in scope. By this time a lake trout and lake whitefish fishery on Lake Athabasca, which had started in 1926, had been discontinued because of some unexplained problem with the fishery and "mesh sizes" (Rawson, 1947*b*). The primary fishing company, McInnes Products Corporation, moved its boats and mobile refrigeration plant, mounted on barges, to Great Slave in 1945 to start the fishery there (Rawson, 1947*b*; Kennedy, 1956). Many of the fishers moved from Athabasca to Great Slave as well (Lorne Penny, pers. comm.). A road to Great Slave at Hay River (**Figure 1**) was completed in 1948, after which some of the equipment was moved back to Lake Athabasca. Extensive fishing had resumed on Athabasca by 1952.

The focus turned more to Great Bear in the late 1950s (Johnson, 1975*a*), even though earlier work had suggested that a commercial fishery on the lake was not feasible (Miller, 1947). As with Rawson's survey on Great Slave, most of the major ecosystem components of Great Bear were included (Johnson, 1964, 1966, 1973, 1975*a*, 1975*b*, 1976). Parallel investigations on Great Slave during this period were restricted largely to the fishery (Keleher, 1963), although there have been brief flurries of activity subsequently in a number of areas (e.g., Keleher, 1972; Patalas and Patalas, 1978; Moore, 1979). However, research in recent decades (e.g., Yaremchuk, 1986) has been minimal, despite the number of large multidisciplinary studies such as the Peace-Athabasca Delta Project (1972), the MacKenzie River Basin Study (1981), the Northern River Basin Study (completed March, 1996), and the MacKenzie Basin Impact Study (this study). Collectively, research over the last half century suggests that the great lakes of the basin are sensitive hence vulnerable to a variety of global change influences.

The MacKenzie Great Lakes lie just to the east of the corridor (**Figure 1**) in which average winter air temperatures increased the most over the 30 year period ending in 1988 (Hengeveld, 1992). In recent years, fish kills in Great

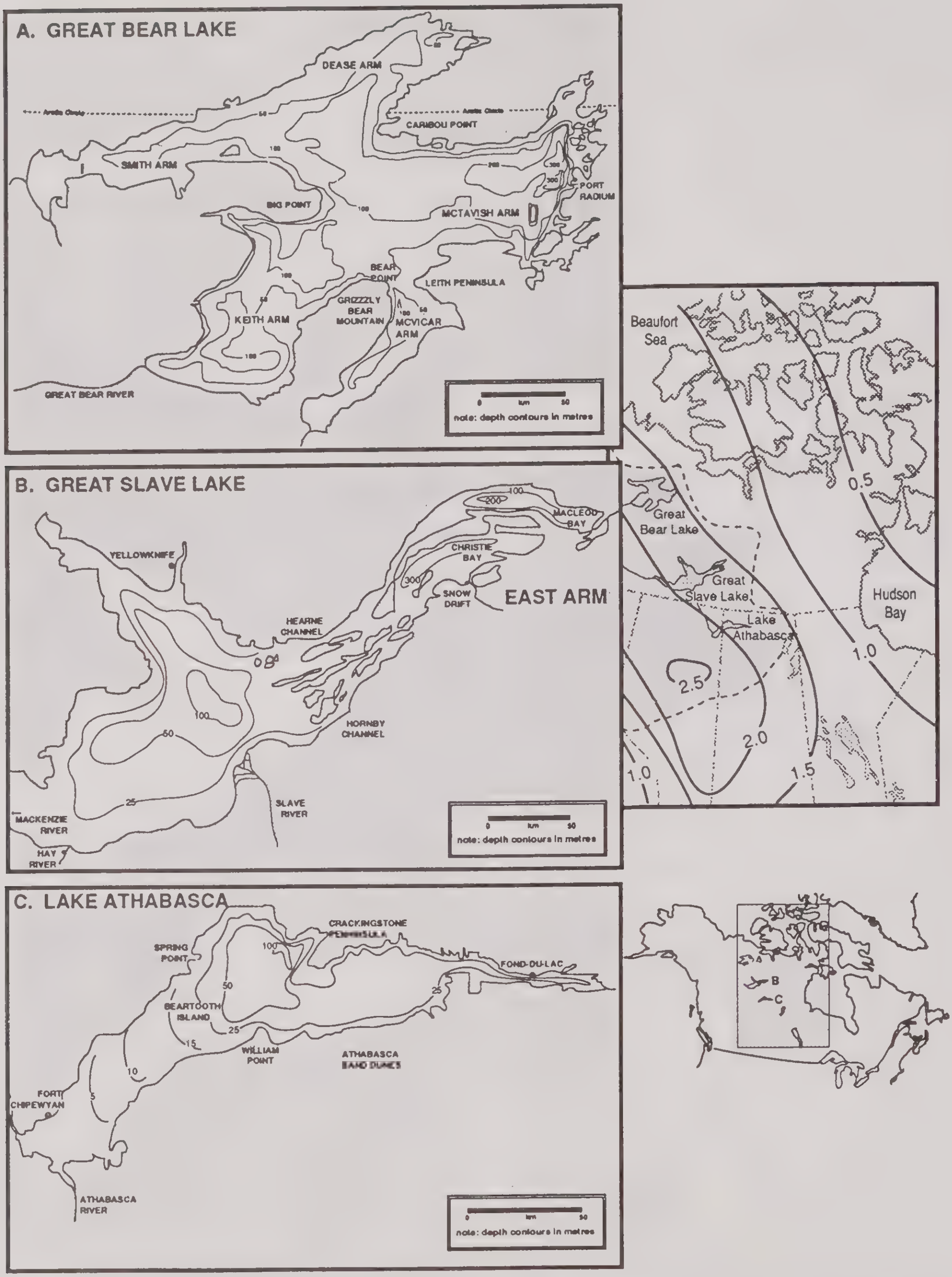

Figure 1. The MacKenzie Great Lakes. Great Bear modified from Johnson (1975*a*), Great Slave and Athabasca modified from Larkin (1948). Intermediate backdrop illustrates positions of the lakes in relation to change in the average winter temperature between two 15-year periods (1959-73 and 1974-88; modified from Hengeveld, 1992); dashed line is the eastern boundary of the MacKenzie Basin.

Slave Lake at the outlet to the MacKenzie River have been attributed to warmer waters, as have increases in fish cullage in the Great Slave commercial fishery (George Low, pers. comm.). Temperature is one of the most important environmental variables for lakes, not only because the rates of chemical and biological processes are usually temperature dependent, but because temperature ultimately determines many of the habitat characteristics in lakes through various physical processes (Fry, 1947; Bennett, 1978). Temperature can also be considered an ecological resource somewhat like food (Magnuson et al., 1979). Projected impacts of changes in temperatures in the basin, occurring with a doubled-CO_2 climate (Rizzo and Wiken, 1992), would undoubtedly affect the MacKenzie great lake ecosystems.

The objective of this study is to assess our ability to determine yields for cold-water fish, specifically lake trout in the MacKenzie Great Lakes, as affected by a changing climate. The process of yield determination in a climate context is currently based on an intermediate step, which includes thermal habitat quantification and prediction:

climate → thermal habitat → yield

Yield calculations *per se* have been based on the relatively simple models of Christie and Regier (1988) for a number of northern commercial species (e.g., Magnuson et al., 1990). For lake trout,

$$\log_{10}SY = 0.807 \log_{10} THV + 0.944 \quad r^2 = 0.86$$

where SY is sustained yield in kg yr^{-1} and THV is summer thermal habitat volume in $hectometres^3$ per 10 days, time integrated from June 5 through September 2. r^2 is the variation explained by the regressions. Thermal habitat is defined as the median preferred temperature ±2°C, the range within which a fish in a preference tank in the laboratory will spend two-thirds of its time. Schlesinger and Regier (1983) proposed the term "sustained yield" (SY) for species-specific estimates of stable maximum catch, values of which were used to compute the regressions. These values are considered to be estimates of the maximum sustainable yield (MSY), however there is no way of determining the extent to which they differ (e.g., Schlesinger and Regier, 1983).

Particular objectives in the study are concerned with the steps in the yield determination sequence; the extent to which water column temperature regimes can be predicted from air temperatures and other environmental variables is examined first, using the example of the East Arm, Great Slave Lake. I propose that the primary predictor of depth-specific temperature in these northern lakes is the average mean daily temperature for some longer previous period; in this study fifty days. Actual and projected thermal responses in great lakes to changes in air temperature have only been studied for those in the temperate zone: Ontario (Rodgers, 1987; Schertzer and Sawchuk, 1990), Erie (Blumberg and DiToro, 1990; Schertzer and Sawchuk, 1990), and Michigan (McCormick, 1990). The remaining objectives are concerned more with underlying subprocesses, particularly the definition and quantification of both thermal habitat and sustained yield of lake trout. I hypothesize that the actual thermal habitats of lake trout in the MacKenzie Great Lakes are substantially lower than the optimal range presented by Christie and Regier (1988), despite their attempts to adjust the range downward. The third hypothesis is that the catch data used by Christie and Regier (1988), the 15-year running average annual catch between 1946 and 1960, do not represent estimates of stable maximum catch, or sustained yield, at least for Great Slave Lake. The index for Great Slave is that of a population in the initial stages of a drastic decline. From another perspective, this study is a sensitivity analysis of an approach which is but an example of similar, large-scale, low-resolution approaches (e.g., Minns and Moore, 1992) which are becoming increasingly common.

For the most part, Lakes Athabasca and Great Bear are compared to Great Slave Lake, because there are data for each of the subject areas only for Great Slave. The fisheries ecology data for Athabasca were never published in any detail, while there has been no commercial fishery on Great Bear. The East Arm of Great Slave, particularly the western half, receives somewhat more emphasis than the main basin. There has not been much commercial fishing for lake trout in the main basin in recent years (D. Archibald, pers. comm), and the eastern half of the East Arm has been closed to commercial fishing since 1974 (Hubert, 1989).

The results of the study should be of use to a broad spectrum of society, including those concerned with environmental conservation and protection, social and cultural issues such as changes to native lifestyles, and economic well-being. For example, salmonid fishes such as lake trout are considered indicators of cold-ecosystem health globally (Maitland et al., 1981). Fishery resources are one of a number of aspects at the heart of native land-claims negotiations. Climatic factors are important in establishing Total Allowable Catches, or TACs; the study could contribute to improvements in the methods of TAC calculation. Agents of change are important to those responsible for developing fisheries management strategies, including formulas for

the allocation of quotas amongst commercial, recreational, and other fishermen. The economic considerations touch all areas of concern because of the dollars involved in fisheries; in recent years, for example, approximately six million anglers have spent eight billion dollars per year on recreational fisheries in Canada (Bailey, 1992), many of the dollars in the MacKenzie basin.

The Lakes

Johnson (1975*a*) presents a concise but comprehensive biophysical account of Great Bear Lake and its setting, while Rawson (1950, 1947*a*) does the same for Great Slave Lake; a less detailed description is presented elsewhere for Lake Athabasca (Rawson, 1947*b*). Based largely on their syntheses, I describe only the most general of system features here, although **Table 1** summarizes a number of specific characteristics for each lake.

The three lakes are oriented northeast-southwest (**Figure 1**), crossing the boundary between the Precambrian Shield to the north and east and the Interior Plain to the south and west. The lakes were formed by the scouring action of the Laurentide ice sheet as it expanded out of the Keewatin during the Pleistocene Epoch. On the shield, the lakes are often bounded by softer rocks to the south and or east, which are surrounded in turn by harder crystalline rocks. Presumably these softer rocks, including sedimentary sandstones, are the outer remnants of large rock fingers which, oriented in the direction of glacier movement, were eroded more than the surrounding crystalline rock. Thus, the glaciers were able to create deep narrow basins on the Shield which then filled with water upon ablation. Off the Shield, the lake basins tend to become broader and shallower; the bedrock here, largely sedimentary limestone, is softer than the crystalline rocks of the Precambrian Shield.

As the continental ice sheet receded, Glacial Lake McConnell, an immense proglacial lake, connected the current MacKenzie Great Lakes. Following retreat of the ice, drainage developed to the northwest around the edge of the Shield, resulting in the pattern we see today. Uppermost in the basin, Lake Athabasca (**Figure 1**) receives most of its water by way of the Athabasca River. Water flows north from Lake Athabasca to Great Slave Lake via the Des Rochers and Slave Rivers, then west out of Great Slave through the MacKenzie River. The Great Bear River drains Great Bear Lake, flowing west to meet the MacKenzie on its way north towards the Beaufort Sea.

Precambrian shorelines are generally steep, rocky and irregular, with many islands in some regions. Shores on the south and west tend to be the opposite: gently sloped, sandy and regular. Most shorelines are exposed to severe wave and ice action, precluding much in the way of emergent vegetation.

Rock outcrops abound in the Precambrian Shield, while soils are sparse. Thin layers of weathered sedimentary rock, glacial till and alluvium can be found in small areas of lower elevation. Soils on the Interior Plain are far more substantial, and occur over thick glacial till. Alluvial and lacustrine deposits occur at lower altitudes. Permafrost, patchy in the south, increases in extent and thickness from south to north.

Table 1. General characteristics of the MacKenzie Great Lakes. Brackets = uncertain or questionable. Data: area, distances, volume from Herdendorf (1982); water, residence time, Great Bear conductivity and total phosphorus Johnson (1975*a*, 1966); ice related, Fisheries and Environment Canada (1978); nutrients, conductivity, Athabasca Secchi, Melville (unpub.); all other from Johnson (1975*a*; see also Miller, 1947) and Rawson (1947, 1950).

	Lake		
	Great Bear	Great Slave	Athabasca
Characteristic		main basin/East Arm	
Drainage basin (1000 km^2)	145.9	958.5	274.6
Total area (1000 km^2)	31.4	28.6	7.9
Shoreline length (km)	2300.	2090.	897.
Length/Breadth (km)	336./177.	456./225.	284./58.
Volume (km^3)	2290.	2090.	110.
Maximum depth (m)	446.	163./614.	124.
Mean depth (m)	72.	41./249.	26.
Water residence time (yr)	124.	7.	(>124.)
Ice-free (d/mo)	15/6-15/7	1/6-15/6//15/6-1/7	15/5-15/6
Frozen (d/mo)	15/10-15/11	15/11-15/12	5/11-15/12
Maximum temperature (°C) common/uncommon	15.5/17.2	16.7/18.6//11./14.	18.9/25.0
Total dissolved solids (mg^1)	82.	149./109.(22, MacLeod Bay)	55.
Conductivity (μmho cm^{-1})	156.	165./(180.)(30, MacLeod Bay)	60.
Total phosphorus (μg1^{-1})	(<10.)	84./4.2	6.6
Total nitrogen (mgl^1)	-	256./248.	6.6
Chlorophyll *a* (μgl^{-1})	-	4.2/2.7	2.0
Maximum Secchi (m)	30.	5.7/17.	9.0

Where forest occurs, white spruce predominates on better well-drained soils, accompanied largely by aspen as one proceeds south. Jack pine is found on sandy soils and rock ridges, while black spruce and tamarack occur in conjunction with poorly drained areas. Trees become increasingly sparse and stunted to the north and east on the Shield. The MacKenzie Great Lakes are oligotrophic (but well oxygenated), to a great extent because the hard crystalline rocks, weathered sandstones, and thin sparse soils and vegetation around much of these lakes contribute very low quantities of nutrients to lake waters.

The climate is northern continental, i.e., cool and subhumid; winters are long and cold and the summers short and cool, although summer temperatures can be much warmer than a northern designation would suggest. In the winter the Arctic air mass dominates the area (Gullett and Skinner, 1992). In summer incursions of Pacific air are common. Annual precipitation is low, about 250-350 mm, with most occurring in late summer and early fall (Gullett and Skinner, 1992). Much moisture is lost by evaporation or evapotranspiration. Northwest and southeast winds predominate. All-in-all, the climatic conditions result in great lakes which are cold, frozen over for half the year or more.

Cold-water organisms dominate the MacKenzie Great Lakes. Salmonids such as lake trout, lake herring (cisco) and lake whitefish are the most abundant larger fish species. Lake trout, the most numerous top carnivores, are found at almost all depths, and consume lake herring as well as other species. Lake whitefish are the most numerous larger secondary consumers, particularly where conditions support ample benthic faunas as food supplies. Typical invertebrates include the glacial relicts *Pontoporeia affinis* and *Mysis relicta,* both important links in coldwater food chains (Larkin, 1948).

Although the MacKenzie Great Lakes have much in common, there are differences between and within the lakes such that environmental gradients exist. Great Bear Lake and the East Arm of Great Slave Lake are deeper than the main basin of Great Slave Lake and Lake Athabasca (**Figure 1**). The west end of Lake Athabasca and to a lesser extent the south and west sides of Great Slave are relatively shallow. Much of the morphometry of the East Arm of Great Slave Lake is very complex, while MacLeod Bay (**Figure 1**) is virtually a separate lake. The bay joins the rest of the East Arm at the Taltheilei narrows, which apparently flows to the southwest hence remains partially open in winter (L. Penny, pers. comm.). Both Great Slave and Athabasca receive huge sediment loads via major rivers from Interior Plain watersheds. These inputs result in extensive highly turbid regions which generally coincide with relatively shallow depths. Trophic status tends to be inversely related to depth at the lake basin scale, although Lake Athabasca appears to be more dilute than the main basin of Great Slave, for example. On a practical level, division of Lakes Athabasca (Chen, 1973) and Great Slave (Keleher, 1972; Hubert, 1989) into different fisheries management areas reflects some of the large-scale biophysical variation within the lakes.

Methods

This study incorporates consideration of seasonality, large-scale spatial differences and interannual variation. All temperature regimes fall within the first half of the open-water period, i.e., May to August, similar to Christie and Regier (1988). The second half of the open-water period is assumed to be a mirror image of the first half, based on the observation that the pattern of surface water temperature cycles in temperate lakes is a symmetrical sine wave (e.g., McCombie, 1967). The spatial distribution of stations (e.g., Melville, 1994) represents regional or large-scale spatial differences within lakes (Boyce, 1974). Regional differences within very large lakes have not been considered in some previous climate change impact projections; implicitly, lakes have been treated as though they are horizontally homogenous (e.g., McCormick, 1990; Robertson and Ragotzkie, 1990). The number of stations sampled in most of the years of this study, including those represented in the literature (e.g., Rawson, 1950), falls within the range used in the Lake Ontario Nutrient Study (LONAS), the Great Lakes International Surveillance Plan (GLISP) (Lean, 1987), and studies of Lake Superior (Schertzer, 1978). Representations of interannual variation are comparable to those used in previous climate-change lake impact projections (Blumberg and DiToro, 1990; McCormick, 1990; Robertson and Ragotzkie, 1990). The number of years of data in previous studies varies between two (Blumberg and DiToro, 1990) and thirty or more (e.g., Schertzer and Sawchuk, 1990; Robertson and Ragotzkie, 1990).

There are water column temperature data, many representing regional differences, from fourteen years spanning half a century for Great Slave Lake (Rawson, 1950, 1956; Patalas and Patalas, 1978; Moore, 1979; this study). There are data from three years for each of Lakes Athabasca (Larkin, 1946; this study) and Great Bear (Johnson, 1966; 1975*a*). In 1992, large-scale three-dimensional temperature synopses of Lake Athabasca were obtained for late spring (mid June), early summer (mid July) and mid-

summer (mid August) in 1992 (Melville, 1994). Temperature measurements were repeated in mid June and mid August, 1993. On Great Slave Lake, temperature profiles were taken at nine stations in 1992, including biweekly profiles at three main basin stations representing current and historical fishing areas (Melville, 1994). Four East Arm stations were visited only in late July-mid August, the late spring-mid summer period in the East Arm region. Logistically, fewer boats are available as the seasons progress on Great Slave Lake and particularly Lake Athabasca, because storms become more frequent starting in late August (e.g., Sortland, 1994). As a consequence, it is more difficult to collect data directly from late August through early December.

Temperature profiles in 1992 and 1993 were taken with Yellow Springs Instrument Co. (YSI) model 5IB (oxygen) temperature meters fitted with YSI model 5739 probes. Specific meter, cable and probe combinations were dedicated to each lake, with a second combination dedicated in each case as backup. Temperatures were measured to the nearest 0.1°C just below the surface of the water (≤0.10 m) and at 1, 3, 5, 10, 15, 25, 35, 50, 75 and 100 m at stations ≥100 m, or as deep as one could measure following the same protocol at stations <100 m. At these shallower stations, the bottom temperature was also recorded. The angle of the instrument cable was kept perpendicular to the surface of the water in most cases, although wind and wave conditions sometimes made this impossible. Temperature measurements were made only if the angle of the cable was <10° relative to the perpendicular at the surface. Other primary data recorded at each station included latitude, longitude, depth and date.

Processing of the raw temperature data involved a number of steps in most cases, with the number of steps varying according to the source of the data. Temperatures measured in 1992 and 1993 were corrected by way of instrumentation-specific regression equations, based on comparisons between laboratory measurements by meter-cable-probe combinations and a standard Kessler thermometer. The thermometer, calibrated in one-hundredths of a °C, is at least an order of magnitude more accurate than the YSI devices. The regression equations were checked by instrument comparisons at the beginning and end of each field season, but did not vary. Unpublished historical YSI data for Great Slave Lake were corrected in a similar manner, via comparisons with more accurate simultaneous thermistor data. These measurements were taken at depths within a metre of the surface. Many data in the literature (Rawson, 1950; 1956) were taken using either bathythermographs or reversing thermometers of unstated accuracy, although the data are reported to the nearest 0.1°C.

Several temperature profiles presented graphically by Rawson (1950) were magnified and digitized so that I could make use of the data. Interpolation was used with linear portions of some profiles from historical sources, where

Table 2. Variables in the multiple linear regression analyses to determine relationships between water column temperature regimes and other variables for the East Arm, Great Slave Lake.

Variable	Definition
dependent	
WATEMP	Depth-weighted mean **WA**ter **TEMP**erature (°C) in a specified depth interval at a sampling station.
independent, large data-set	
DEPTHINT	**DEPTH INT**erval (0-5 m, 5-35 m, 35-100 m) referred to with respect to mean water temperature (**WATEMP**).
LAT	Station **LAT**itude (metric units)
LONG	Station **LONG**itude (metric units)
SHORDIS	**DIS**tance (km) between a sampling station and the nearest **SHOR**e.
PINFLOW*	Distance (km) between a sampling station and the nearest land proximal to the **P**rimary riverine **INFLOW.**
SINFLOW*	Distance (km) between a sampling station and the nearest land proximal to the main **S**econdary riverine **INFLOW.**
DEPTH	Surface-to-bottom **DEPTH** (m) of sampling station.
YEAR	**YEAR** water temperatures sampled.
DATE*	Julian **DATE** water temperatures sampled.
AIRTEMP1	Mean daily **AIR TEMP**erature (°C) at the nearest climate station for the day preceding water temperature sampling.
AIRTEMP2	Average mean daily **AIR TEMP**erature for the 10 days preceding water temperature sampling.
AIRTEMP3	Average mean daily **AIR TEMP**erature for the 30 days preceding sampling.
AIRTEMP4	Average mean daily **AIR TEMP**erature for the 50 days preceding sampling.
independent, small data-sets	
WINDSPD1	Mean daily **WIND SP**ee**D** (km/h) at the nearest climate station for the day preceding water temperature sampling.
WINDSPD2	Average mean daily **WIND SP**ee**D** for the 10 days preceding water temperature sampling.
WINDSPD3	Average mean daily **WIND SP**ee**D** for the 30 days preceding sampling.
WINDSPD4	Average mean daily **WIND** SPee**D** for the 50 days preceding sampling.
WINDDIR	Modal daily **WIND DIR**ection (one of 8 compass points) at the nearest climate station for the 30 days preceding water temperature sampling.

*correlated with one or more other variables

temperatures had not been measured for some of the depths chosen in this study. Where temperature patterns in some historical data sets (Rawson, 1950) could not be determined, the data were not included in this study.

Following preliminary processing of the temperature data, depth-weighted mean temperatures were calculated for the different depth strata (DEPTHINT, **Table 2**) in each profile from the East Arm of Great Slave Lake. An intermediate step was to calculate the mean temperature for each depth interval in each profile from depth-specific data. The 35 m depth represents the approximate lower limit of the zone on Great Slave which has been commercially fished in recent years, although primarily for whitefish (L. Penny, pers. comm.). A depth of 100 m has been the approximate lower limit of the western East Arm trout fishery.

Empirical or multivariate statistical models are used to determine relationships between water column temperature regimes, air temperatures, and other environmental variables for the East Arm, Great Slave Lake. These methods make use of responses to variables which have occurred in the past. The variables in analyses to determine relationships between water column temperature regimes and key environmental factors are defined in **Table 2**. The temperature regimes constitute the variable WATEMP, while the depth intervals they represent make up the variable DEPTHINT (**Table 2**) discussed previously. Meteorological considerations focus on air temperature and wind speed, factors which exert a major influence on water temperatures (e.g., Robertson and Ragotzkie, 1990). Meteorological data from the Yellowknife climate station (Etkin, 1991) were obtained from the Atmospheric Environment Service of Environment Canada. Of the other variables (**Table 2**), for example, SHORDIS and PINFLOW, both known to have an effect on temperatures (Rawson, 1960), were measured from nautical charts using the latitude and longitude data.

All ecological data pertaining to lake trout were obtained from the legacy of survey work referred to in the Introduction. Ecological data for Great Bear Lake were obtained from Johnson (1975*b*), while Great Slave Lake data were derived largely from Rawson (1950; 1956), Kennedy (1954), Keleher (1972), and Hubert (1989). Gill nets used in the ecological surveys were similar in each case; each net consisted of a set or standardized subset of 45.7 m panels representing a similar range of mesh sizes. Lake Athabasca fishery data were provided by Saskatchewan Environment and Resource Management, although the first few years of the fishery are documented only in Rawson (1947*b*). Some lake trout data in graphical form were magnified and digitized as well.

Sokal and Rohlf (1969) and Wilkinson (1985) are used as statistical references throughout this paper.

Results

Maximum temperatures in the water column down to 100 m decrease in the sequence Athabasca → Great Slave → Great Bear (**Figure 2**), as one would expect based on latitude. The highest recorded midsummer surface temperatures (**Table 1**) follow the same pattern (**Figure 2**). There is substantial overlap within and between years (e.g., **Figure 2**) as well as between lakes. In the water column, temperatures and temperature changes with depth are highest within the top 5-10 m. More gradual changes occur between 5-10 m and 35 m, below which gradients are minimal. Midsummer temperatures can often reach 15-18°C (**Table 1**) in shallow more protected areas, as well as in areas of riverine inflow. However, in the relatively shallow

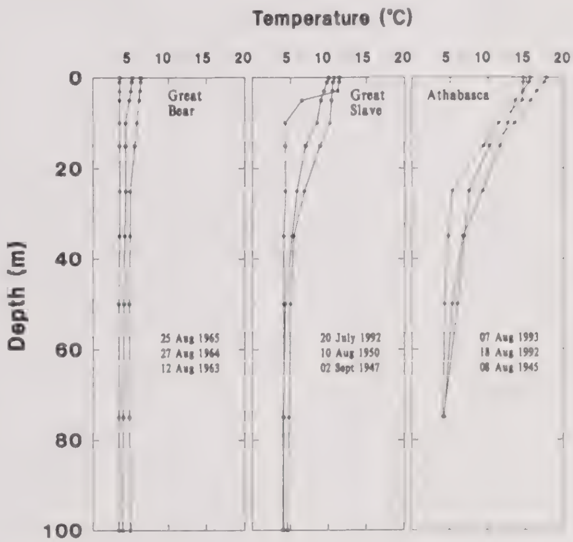

Figure 2. Representative temperature-depth profiles to a maximum of 100 m for selected offshore (2.5-9.5 km) sites in the MacKenzie Great Lakes. Temperatures are the warmest measurements available for the offshore regions in the years indicated. Date labels, top-to-bottom, correspond to profiles in panel, viewed left-to-right at 40 m. El Niño years, 1965, 1992, 1993; average years, 1945, 1947, 1963; La Niña years, 1950, 1964 (see text). Data sources: Great Bear, north and east McTavish Arm, Johnson (1975*a*); Great Slave, north shore by Gros Cap, west of Hearne Channel, Rawson (1950) and this study; Athabasca, north shore near St. Josephs Point, west of Crackingstone, Larkin (1946) and this study.

Table 3. Summary statistics for comparisons of temperatures within depth intervals (WATEMP) between stations ≤115 m and >115 m in a small data set for the East Arm of Great Slave Lake. Data sources: Rawson (1950, 1956) and this study.

	Depth interval (DEPTHINT, m)/Station depth (m)					
	0 - 5		5 - 35		35 - 100	
Statistic	≤115	>115	≤115	>115	≤115	>115
Number of cases (n)	16	39	15	39	11	39
Mean	8.6	6.3	6.0	4.9	4.2	3.9
Standard deviation (SD)	4.1	3.3	2.7	1.9	0.9	0.9
F-ratio (F)	4.776		2.646		0.718	
Probability (P)	0.033		0.110		0.401	

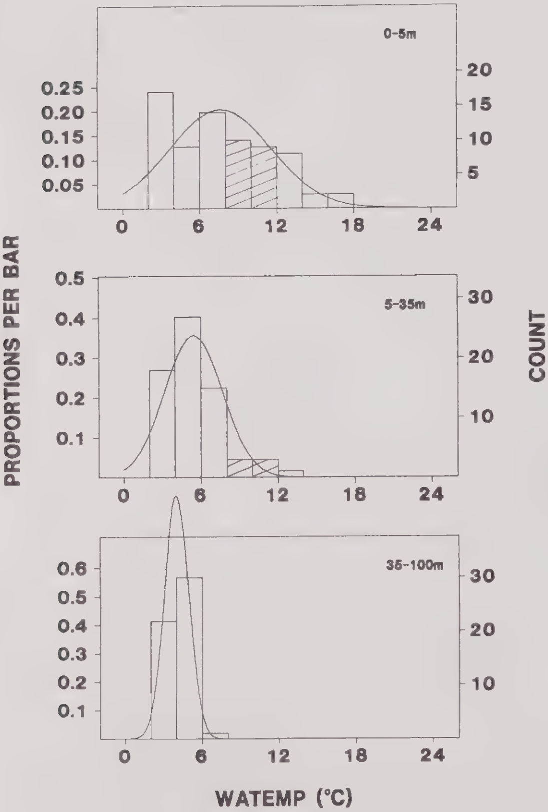

Figure 3. Density distributions, discrete and continuous, of mean water temperatures in three depth intervals (WATEMP, Table 2) in the East Arm of Great Slave Lake. Diagonal-hatched is the optimal thermal habitat for lake trout as defined by Christie and Regier (1988). Data sources: Rawson (1950, 1956) and this study.

western part of Athabasca, temperatures reached 16°C at only one station on one date during the summers of 1992 and 1993. The profiles in **Figure 2** were chosen in part because some of the years correspond to phases in the El Niño-Southern Oscillation. Of note, temperatures in profiles for warm or El Niño years are cooler than those in cooler or La Niña years (**Figure 2**).

Temperature density distributions in the East Arm of Great Slave Lake indicate that even in the 0-5 m depth interval, the warmest stratum, only a relatively small proportion (<30%) can be categorized as optimal lake trout thermal habitat, 8-12°C, according the definition of Christie and Regier (1988). This proportion drops to about 10% in the 5-35 m interval, and zero below it. The greater part of each density distribution for the three depth intervals is below 8°C, the lower limit of the optimal thermal range. Comparisons of interval-

Table 4. Summary of multiple regression analyses (e.g., Figure 4) which best relate water column temperature regimes (WATEMP) to other variables (Table 2) for the East Arm, Great Slave Lake. Data sources: Rawson (1950, 1956) and this study.

Depth interval (DEPTHINT, m)	Independent variable	Coefficient	P	n	r^2
Large data-set					
0 - 5	CONSTANT	157.	0.000	71	0.668
	AIRTEMP4	1.29	0.000		
	LAT	-4.19	0.000		
	YEAR	-0.078	0.000		
	DEPTH	-1.60	0.114		
5 - 35	CONSTANT	107.	0.000	56	0.711
	AIRTEMP4	0.797	0.000		
	LAT	-252.	0.000		
	YEAR	-0.053	0.000		
	SHORDIS	-0.229	0.006		
35 - 100	CONSTANT	26.7	0.026	53	0.525
	AIRTEMP4	0.311	0.000		
	LAT	-0.813	0.008		
	YEAR	-0.012	0.038		
Small data-sets					
0 - 5	CONSTANT	675.	0.007	44	0.710
	AIRTEMP4	1.26	0.000		
	WINDSPD4	-2.73	0.007		
	LAT	-3.62	0.010		
	YEAR	-0.32	0.000		
5 - 35	CONSTANT	475.	0.004	30	0.883
	AIRTEMP4	1.05	0.000		
	WINDSPD4	-1.37	0.025		
	LAT	-1.69	0.001		
	YEAR	-0.23	0.003		
	SHORDIS	-0.20	0.023		
35 - 100	CONSTANT	26.7	0.026	53	0.525
	AIRTEMP4	0.311	0.000		
	LAT	-0.813	0.008		
	YEAR	-0.012	0.038		

specific temperatures (WATEMP) between stations ≤115 m and >115 m in the East Arm (**Table 3**), for which wind speed data are available, indicate that temperatures are significantly cooler in the 0-5 m interval at the deeper stations (P=0.033, ANOVA, n=55). These two categories were chosen because 115 m is close to 100 m, and there is a larger break below 115 m in the frequency distribution of depths sampled. The 0-5 m distribution underestimates the frequency of warmer temperatures which probably occurred in very shallow areas (**Figure 3**), because fewer historical data for such stations were ultimately available for inclusion in the data set. Very shallow areas in particular represent a tiny proportion of the East Arm.

As proposed, the best predictor of water temperatures in the three depth intervals is the average air temperature over the previous fifty days (AIRTEMP4, **Table 4**). Two other variables, latitude and year, also contribute to the regressions (**Table 4**). The smaller data sets containing wind speed increase the r^2, the variation explained by the regression, only for the 5-35 m depth interval. Four variables (**Table 2**) are highly correlated with one or more of the remaining variables, hence were dropped after preliminary analyses. Overall, the multivariate regressions including air temperature and excluding wind speed explain about two-thirds of the variation in water temperature in depth strata down to 100 m.

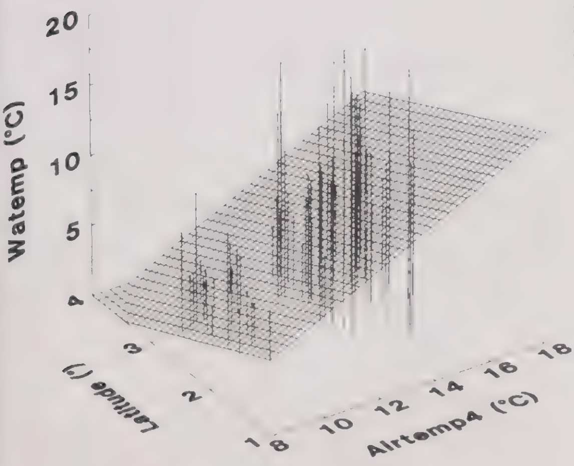

Figure 4. Mean water temperature (WATEMP) for the 5 - 35 m depth interval in relation to mean air temperature for the previous 50 d at Yellowknife (AIRTEMP4) and latitude (LAT) for the East Arm, Great Slave Lake (see Tables 2, 4). Vertical lines join data points to the x-y plane. Data sources: Rawson (1950, 1956) and this study.

Lake trout had similar depth distributions between 0 m and 100 m in Great Slave and Great Bear Lakes (**Figure 5**; P>0.1 Friedman's randomized block test, c^2=12.26). Trout numbers peaked between 26 m and 35 m in Great Slave, and slightly deeper, 36-45 m, in Great Bear.

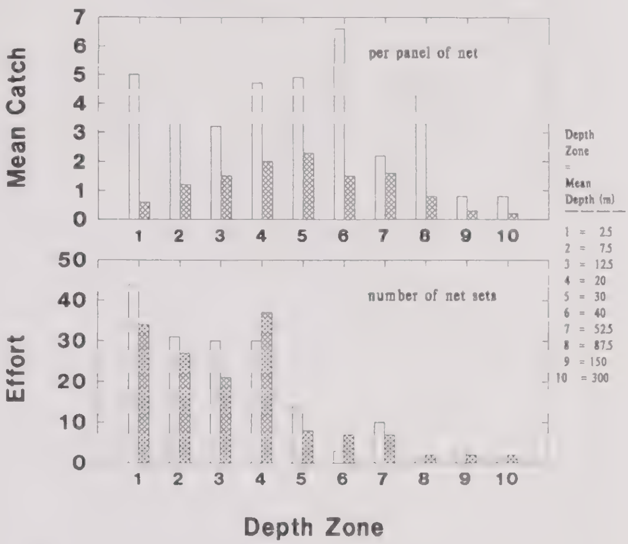

Figure 5. Lake trout catch per 45.7 m panel of gill net, and number of net sets, by depth zone for Great Bear and Great Slave Lakes. Open bars = Great Bear; Cross-hatched = Great Slave. Data sources: Great Bear, Johnson (1975*b*); Great Slave, Rawson (1951).

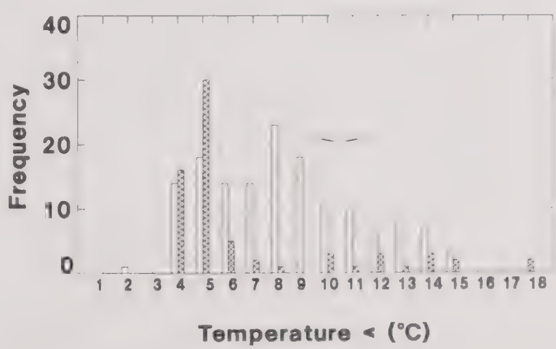

Figure 6. Frequency of near-bottom water temperatures corresponding to lake trout net-set zones in Great Bear and Great Slave Lakes. Bracket is the optimal thermal habitat of Christie and Regier (1988). Open bars = Great Bear; Cross-hatched = Great Slave. Data sources: Great Bear, Johnson (1975*b*); Great Slave, Rawson (1950, see also Moore, 1979).

The distribution of fishing effort with depth (**Figure 5**) was comparable in the surveys by Johnson (1975*b*) and Rawson (1951) (P>0.9, RxC test of independence, G=7.24). Effort decreased in roughly an exponential manner with depth (**Figure 5**), corresponding to the general relationship between depth and area-weighted volumes of depth intervals.

Temperature distributions in the netting zones of Great Bear and Great Slave Lakes (**Figure 6**) both peaked below the range of optimal thermal habitat. Otherwise the distributions were substantially different (**Figure 6**; P<0.01, RxC test of independence, G=35.7). The frequency of temperatures peaked at 8°C in Great Bear Lake, but at only 5°C in Great Slave (**Figure 6**). Only 10% of zone temperatures for Great Slave occurred in the optimal range, while about 30% of the Great Bear temperatures were included. Note that **Figure 5** contains several high temperatures representing shallow inshore areas, e.g., Yellowknife Bay, taken from Moore (1979). The frequency distribution for Great Bear resembles the broader density pattern for the 0-5 m depth interval of the East Arm, Great Slave Lake (**Figure 4**). The distribution for Great Slave as a whole, a narrow band of high frequencies, is more like the distribution for the 35-100 m depth interval in the East Arm.

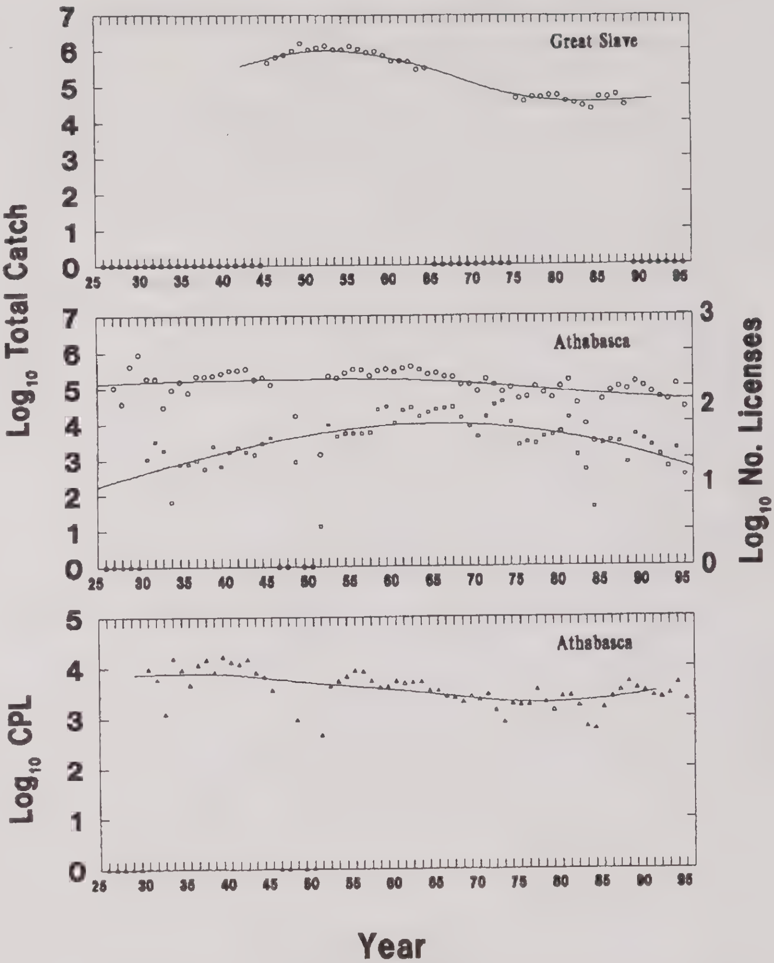

Figure 7. Yearly lake-trout fishery data for Great Slave and Athabasca Lakes since the fisheries started. Curves fitted by distance-weighted-least-squares allowing flection or adaptation to different patterns occurring over shorter periods of several years. Years of no catch: 1946, 1947, 1949, 1950, during changes in the fishery omitted from curve fits. Second panel, circles = $\log_{10}$ lake trout catch (kg); squares = number of licenses. Third panel, CPL = lake trout catch per license. Data sources: Great Slave, Keleher (1972) and Hubert (1989); Athabasca, this study.

On average, about three times as many trout were caught per panel of net per depth zone in Great Bear Lake as in Great Slave Lake (**Figure 5**, P<0.005, Wilcoxon signed-ranks test, T_s=0) at the start of the fishery. Nets were set for just 16 h in Great Bear Lake, versus 24 h in Great Slave, although sets in both lakes included evening, night and morning periods. Other minor differences in gill net specifications, e.g., net height at smaller mesh sizes, were corrected by reducing the trout catch per depth zone by 20% in Great Bear Lake. Mean catches ranged from 13.3-21.8 trout per six panels of net in the East Arm of Great Slave Lake, including the Hornby Channel. Catches there were two to three times higher than the average in the main basin, 6.1 trout per six panels. The high of 21.8 trout, the mean catch from Christie Bay, Great Slave Lake, equals the corrected mean catch from Great Bear Lake, excluding potential spawning aggregations. Rawson (1947*a*) indicates that the average catch of lake trout in Lake Athabasca, albeit from a population which

had been exploited for a longer period of time, was similar to catches from the main basin of Great Slave Lake.

Graphs in Rawson (1951) and Johnson (1973) suggest that on the whole, lake trout in Great Bear Lake were longer than those in Great Slave Lake when the fishery started. Maximum, modal and minimum lengths were only slightly longer, however body lengths were more evenly distributed over the range of sizes in Great Slave Lake, resulting in more smaller fish in particular. Smaller trout were proportionately most abundant in the East Arm.

After initiation in 1945, the Great Slave trout fishery peaked in the early 1950's, then began to decline in dramatic fashion (**Figure 7**). This trend, delineated by distance-weighted-least-squares, continued through to the end of the data sequence (1988). The highest mean catch of trout over five years was 1,198,000 kg between 1951 and 1955, while the lowest was 76,300 kg between 1981 and 1985, a span of 30 years. A second-order polynomial also describes the Great Slave data (**Figure 7**) very well, explaining 98% of the variation in the regression. Keleher (1972) showed that fishing effort increased substantially through the initial stages of the decline, then subsided in several fishing areas as the catch decreased. Catch per unit effort declined drastically.

Catch data for the western portion of the East Arm, compiled in the draft management plan (Hubert, 1989), show that by 1988 the trout catch was a fraction of what it had been in the early years of the Great Slave fishery. The catch dropped from an average of 464,000 kg between 1945 and 1954 to an average of 62,100 kg between 1972 and 1988 ($P < 0.001$, Wilcoxon two-sample test, $U_s = 170$). Catch per unit effort shows the same downward shift, from an average of 67.2 kg per net per 24h between 1945 and 1954 to an average of 11.7 kg per net per 24h between 1978 and 1988.

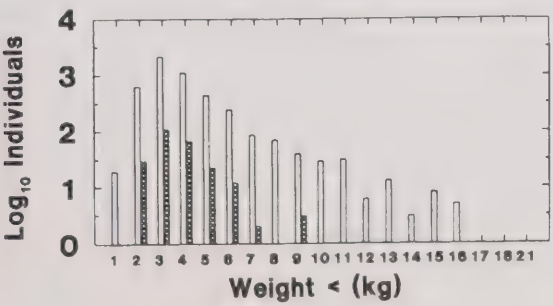

Figure 8. Body weight frequencies over two periods for lake trout from the western East Arm of Great Slave Lake. Open bars = 1945-1952; cross-hatched = 1988. $Log_{10} = 0$ at 17, 18, and 21 kg. Data sources: 1945-1952, Keleher (1972); 1988, Hubert (1989).

Larger trout > 10 kg were also taken far less frequently in 1988 than from 1946 to 1952 in the western East Arm, in contrast to trout <10 kg (**Figure 8**) ($P<0.001$, 2x2 test of independence, $G=14$). Log_{10} frequencies were multiplied by 10 and rounded to remove decimals. The upper limit had dropped by about 60%, to a maximum of 9 kg from a maximum of 21 kg.

Changes in the Lake Athabasca trout fishery paralleled those in the fishery of Great Slave Lake, although they initially tended to occur more slowly (**Figure 7**). For the most part, higher catches occurred between the early 1940's and the early 1960's, but dropped thereafter (**Figure 7**). The highest mean catch over five years was 328,000 kg between 1958 and 1962, while the lowest was 64,700 kg between 1974 and 1978, a span of only 20 years. The number of licenses increased through the higher-catch period, peaking in the 1960's, after which the number decreased (**Figure 7**). As a consequence, the catch per license dropped through the early 1980's. The minimum catch per license in the early 1980's coincided with the financial deficit and closure of the Freshwater Fish Marketing Corporation processing plant at Gunnar on the Crackingstone Peninsula (unpub. manuscript). The catch has been variable since then, but has remained small, averaging 62,100 kg. Major decreases in all fishery statistics coincided with the hiatus in the fishery starting in 1946. Earlier, the catch plummeted in 1930, after rising very sharply from the start of the fishery, 1926, through 1929.

Only anecdotal observations are available with respect to the sizes of individual trout in the Athabasca fishery, although a few have been very large; a trout 106 lbs or 48.2 kg was reportedly taken in 1961 (Smith, 1981) at the height of the commercial fishery.

Conclusions

We cannot forecast the potential effects of climate change on sustained yields of cold-water fish, in this case lake trout in the MacKenzie Great Lakes. There are too many major knowledge gaps in fisheries ecology for us to be attempting to predict such yields without substantial further research. Many aspects of water column thermal prediction in a climate context can be improved considerably, while improved methods of thermal habitat quantification and sustained yield analysis are essential.

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Climate Change: Proposed Effects on Shorebird Habitat, Prey, and Numbers in the Outer Mackenzie Delta

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Abstract

Shorebirds (sandpipers, plovers, snipe, godwits, curlews) are dependent on shallow water habitats for foraging, so their populations are vulnerable to even small changes in climate. Most North American species of shorebirds breed in the arctic, and ten species breed commonly in the outer Mackenzie Delta.

Timing of breeding, availability of suitable habitat, and invertebrate prey densities of Mackenzie Delta shorebirds may be affected by a number of factors, including timing of ice breakup, extent and frequency of flooding of the outer delta, distribution of permafrost, amount of coastal erosion, summer precipitation, and evaporation rate. Changes in the synchrony of habitat and prey availability in the arctic with prey availability at migratory staging areas farther south may also be important in assessing potential effects of climate change. Many of the potential changes in these abiotic factors have been examined by other MBIS participants; this paper discusses their implications for shorebirds breeding in the outer Mackenzie Delta.

From these scenarios it appears that there will be little priority shorebird habitat lost in the area through coastal erosion during the next 50 years. An increase in the active layer, potentially less frequent complete inundations of the delta, and an increased evaporation rate may eventually result in fewer shallow wetlands throughout the outer delta, particularly in late summer. With warmer temperatures, a greater proportion of insects are likely to be Culicidae rather than Chironomidae, but both are shorebird prey. A decrease in shorebird numbers in the delta is likely to occur with the most common and most aquatic species, the Red-necked Phalarope. Numbers of Common Snipe will likely increase due to an expansion of dense willow habitat. Populations of species nesting in drier habitats of sparse vegetation, such as Semipalmated Sandpipers and Lesser Golden Plovers, may also increase slightly. Numbers of other species are expected to remain fairly constant. Many Mackenzie Delta shorebirds stage in prairie Canada during spring and/or fall migration. With drier conditions in that region there may be some loss of habitat, particularly in the fall, but large shallow lakes and managed wetlands should be able to support these shorebird populations for some time.

Introduction

Shorebirds (Order Charadriiformes, suborder Charadrii) are a diverse group of birds, including plovers, sandpipers, phalaropes, snipe, godwits and curlews. Most species in North America are found primarily in wetland or coastal areas. These birds are highly migratory, flying north in the spring (May to early June) to breeding areas, and south to the southern United States, Central and South America in the fall (July to September). Shorebirds feed primarily on aquatic insects and intertidal invertebrates (Brooks 1967, Holmes and Pitelka 1968, Baker and Baker 1973, Baker 1977, Lewis 1983).

Of the 40 species of shorebirds breeding regularly in Canada, 65 percent (26 species) breed almost exclusively in the arctic or subarctic (Godfrey 1986). Shorebirds are an important component of tundra ecosystems, serving as major predators of small invertebrates, and prey of many avian and mammalian predators such as hawks, owls and weasels. Particularly in years when densities of small mammals such as mice and voles are low (about every 3-4 years), shorebird eggs and young are an alternative source of food for foxes and other predators (Norton 1973, Gratto-Trevor 1994a).

Temperature increases due to global climate change are expected to be greatest in northern regions (Roots 1990). Since the breeding range of most North American shorebirds is restricted to arctic Canada and Alaska, any major impact on habitat in these areas could have severe effects on population levels of entire species. Since most species are associated with shallow wetlands, shorebirds are an excellent indicator group for modelling the effects of climate change on wildlife populations.

Most shorebirds breeding in the Mackenzie delta nest above the treeline, so this study concentrates on potential effects of global climate change in the outer delta. Ten species of shorebirds breed commonly in the area, including (in order of abundance), Red-necked Phalaropes *(Phalaropus lobatus)*, Common Snipe *(Capella gallinago)*, Semipalmated Sandpipers *(Calidris pusilla)*, Pectoral Sandpipers *(Calidris melanotos)*, Stilt Sandpipers *(Calidris himanto-*

pus), Long-billed Dowitchers *(Limnodromus scolopaceus),* Semipalmated Plovers *(Charadrius semipalmatus),* Lesser Golden Plovers *(Pluvialis dominica),* Hudsonian Godwits *(Limosa haemastica),* and Whimbrel *(Numenius phaeopus)* (Gratto-Trevor 1994b, Gratto-Trevor 1996).

The only known breeding area of Long-billed Dowitchers in Canada is in the Mackenzie Delta area. In addition, a number of species, including Whimbrel and Stilt Sandpipers, appear to breed in only two regions in Canada: along the northwest coast of Hudson Bay, and in the Mackenzie Delta area. Therefore the delta may represent the entire breeding range for some populations. This is particularly true for the Hudsonian Godwit, which breeds only in a few localized areas in Alaska and arctic Canada, and nowhere else in the world (Godfrey 1986). The only known breeding records for the Eskimo Curlew *(Numenius borealis),* which is currently nearly extinct, were just west of the Mackenzie Delta, near Anderson River (Gollop et al. 1986). There have been several sightings of Eskimo Curlew in the last ten years in the outer Mackenzie Delta itself (Dickson et al. 1989). Therefore this region may hold the last extant breeding paris of the species.

Arctic shorebirds are vulnerable to climate change primarily by indirect effects on habitat and invertebrate prey. Many of the potential changes in abiotic factors that would affect habitat and prey have been examined by other MBIS participants. Their implications for shorebirds breeding in the outer Mackenzie Delta are discussed below.

Breeding Habitat

Important habitat for breeding shorebirds was determined by censusing shorebirds in 200 X 200 m plots of different habitat types throughout the outer delta. Except for Semipalmated Plovers, which nested on gravel beaches, and snipe, which were sometimes found in dense willow, most shorebirds nested in areas of 'pure' sedge, low-centre polygons (patterned ground), or low tussocky tundra. Red-necked Phalaropes in particular were usually found in wet sedge areas, while species such as Lesser Golden Plovers and Semipalmated Sandpipers nested in somewhat drier areas such as low tussocky tundra (Gratto-Trevor 1996).

Flooding frequency, duration, rate of sediment deposition, and erosion rates are important in determining vegetation present in the delta. Poplars and spruce are found in areas of infrequent flooding and little sediment deposition, while *Equisetum,* sedge *(Carex),* and willow *(Salix)* exist in areas where flooding and siltation are most severe. Areas with spruce and alder currently flood only once in five or ten years, for only two or three days at a time. Willow/alder habitats are flooded two to five years out of ten, and can survive up to a month of flooding. Areas dominated by herbaceous plants flood annually, for up to 50 days or more per year. Silt deposition is much lighter at higher elevations, but can be heavy in low *(Equisetum)* areas (Hirst et al. 1987). Low-centre polygons are common in areas that are poorly drained, in regions of continuous permafrost (Ritchie 1984).

Spring Flooding

The amount of ice cover on delta channels and May/June temperature regimes determine the extent of spring flooding. Thermal breakups resulting from warm springs occur in most years, and are characterized by short-term ice jams, flooding only the northern and central regions of the delta for a short period of time. Mechanical breakups are less common, occurring in years of low spring temperatures. Virtually the entire delta is flooded, with high water levels remaining for about ten days (Bigras 1990). With warmer winter temperatures from global climate change, the ice is expected to be less thick, so even if winter precipitation increases, slightly lower peak flows are expected, and an earlier spring peak (Lawford and Cohen 1991). Warmer spring temperatures and less ice would presumably result in less frequent inundation of the entire delta, and duration of flooding would be less (fewer years of mechanical breakup).

Coastal Erosion

The Beaufort Sea coastline is slowly submerging at a current sea level rise of 3 mm per year or less (Solomon et al. 1993). On average, erosion occurs at the rate of 1-2 m per year, with some areas up to 10-20 m per year. In addition, storm surges resulting from strong onshore winds can affect water levels as far south as Inuvik. Storm surges are most common in late summer (Blasco 1991). Changes in sea level rise due to global climate change are expected to be greatest in areas where the coast is submerging and where the coastal area is made up of ice-rich unconsolidated sediment with a gentle slope, as is the Mackenzie Delta (Egginton and Andrews 1989). In this region, the rate of sea level rise may more than double (Solomon et al. 1993). With an expected increase in the open water season from 60 to 90 days, deepwater wave height would be increased by 22 to 39%, assuming no change in storm frequency or intensity (McGillivray et al. 1993). In fact, summer storm frequency and intensity are expected to increase, adding to increased rates of coastal erosion (Law-

ford and Cohen 1991). However, coastal erosion is currently very slow in the region north of the highest concentrations of priority shorebird habitat (Taglu area of Richard's Island). In 50 years, erosion would currently amount to only about 100 m (S. Solomon, pers. comm.). Even if this erosion rate triples due to potential increases in storm events and higher ocean levels, it should not encroach greatly on priority shorebird nesting habitat (Gratto-Trevor 1994b).

Permafrost and the Active Layer

The outer delta is a region of continuous permafrost. In dwarf willow/sedge areas, the active layer of the soil averages 30 to 38 cm in depth, 25-61 cm in areas of sedge-herb, and for low-centre polygons, 25 cm in the damp to wet centre and 30 cm on the drier rims (reviewed in Slaney and Co. Ltd. 1974). Melting of permafrost could result in the formation of new lakes or increase the surface area of existing lakes, as areas of ice-rich soil slump and become filled with water (Mckay 1992, Oswood et al. 1992). However, no real changes in permafrost are expected in the outer delta, even if increased snowfall results in greater insulation. Nevertheless, the active layer should deepen by about 50 percent (L. Dyke, pers. comm.). Changes in the active layer may lead to decreases in soil moisture and eventually declines in total area of wetlands throughout the arctic (Kane et al. 1992). A deeper active layer may also speed changes in vegetation patterns in the delta (Lawford and Cohen 1991).

Summer Precipitation and Evaporation

Expected increases in evapotranspiration rates and possible decreases in summer precipitation, flood frequency and flood duration may result in some wetlands shrinking or possibly drying up completely, including some lakes (Lawford and Cohen 1991, Marsh and Lesack 1992, Smith 1993). At least temporarily, some of this loss in shallow water habitat may be offset by the gradual drying of deeper ponds and lakes.

Food Availability

Arctic

In the arctic, shorebird adults and older young feed primarily on aquatic invertebrates, particularly Dipteran larvae. Shorebird young, in their first week or two after hatch, feed almost entirely on small-sized adult insects, usually Dipterans. Peak shorebird hatch on the tundra is timed to coincide with peak emergence of Dipteran imagines (Holmes 1966, Holmes and Pitelka 1968, Holmes 1972, Baker 1977).

In the outer Mackenzie Delta, an examination of invertebrates from shallow ponds in different habitats indicated that aquatic Dipterans were most common in wet sedge-willow habitats, compared to low tussocky tundra, low-centre polygons, mudflats, 'pure' sedge, high upland tundra, or dense willow habitats (Gratto-Trevor 1994c). Shallow water is a very favourable habitat for insects in the arctic since it heats rapidly from solar radiation but cools slowly due to the high specific heat of water (Danks 1992).

Invertebrate communities could be greatly altered by temperature and vegetation changes (Danks 1992, Oswood et al. 1992). For example, while mosquitoes (Culicidae) are very common in lower arctic regions, they are greatly outnumbered by midges (Chironomidae) farther north. Insects, being very mobile, can rapidly colonize previously unsuitable areas as they become favourable via climate change. The timing of mosquito and midge emergence is highly temperature dependent (Danks and Oliver 1972, Corbet and Danks 1973), so an earlier onset of warmer temperatures would result in an earlier insect hatch (Sweeney et al. 1992). If shorebirds can compensate by migrating north earlier, shorebird hatch could still be timed for peak insect hatch (prey necessary for chicks).

A change in invertebrate species composition would not necessarily affect breeding shorebirds. These birds often forage on a variety of prey types at different locations along their migratory pathways, in both marine and freshwater habitats (Brooks 1967, Holmes and Pitelka 1968, Baker and Baker 1973, Baker 1977, Lewis 1983). Both mosquitoes and midges are shorebird prey.

Migration

Arctic shorebirds are long-distance migrants, dependent on food resources elsewhere at specific times of the year. If the timing of food flushes elsewhere (e.g. horseshoe crab eggs at Delaware Bay) changes more slowly (as expected) than invertebrate regimes in the arctic, the birds may not be able to migrate early enough to hatch eggs before peak insect hatch (Lester and Myers 1991).

Foraging habitat at staging areas may also be affected by climate change. Shallow nonpermanent wetlands are necessary for shorebird feeding, and are extremely vulnerable to loss from increases in global temperatures, particularly in the Prairies or Great Plains (Diamond and Brace 1991). More shallow, temporary and seasonal wetlands in the interior of North America may be plowed under for agricultural use as well. However, increases in salinity of drying ponds may benefit shorebirds for two reasons. Invertebrates are often abundant under saline conditions, and

the reduction in emergent vegetation will make sites more favourable for foraging shorebirds (Poiani and Johnson 1991).

Many Mackenzie Delta shorebirds migrate through the prairies (unpubl. data). Even increased drought there should not dangerously reduce foraging opportunities during spring migration. Loss of habitat would be greater in the fall, but fewer shorebirds appear to use the prairies at that time (many fly southeasterly from the north), so the remaining large shallow natural and managed wetlands in the prairies should be able to support those that do migrate south through the interior, at least for some time.

Conclusions

Although coastal erosion is unlikely to encroach greatly on priority shorebird nesting habitat in the outer Mackenzie Delta in the next 50 years, ultimately a deepening of the active layer, increased evaporation and evapotranspiration due to higher temperatures, and potentially decreased July precipitation should result in a net loss in wetland habitat, and earlier drying of tundra ponds. If flooding regimes are changed so that areas of the delta are less often inundated, shallow wetland habitats would also be expected to decline. This loss is not expected to be offset, except temporarily, by the gradual drying up of deeper ponds and lakes, or by slumping sediments forming shallow tundra pond habitat.

Effects of changes in invertebrate prey are less predictable, but may not greatly affect these migratory birds, as they forage on varying types of invertebrates during their annual cycle. Mackenzie Delta shorebirds primarily migrate north through the prairies, so may be able to adapt to an earlier insect hatch in the arctic by advancing their spring migration dates.

Höhn (1959) compared observations of nesting birds just east of the outer Mackenzie Delta, from an 1860 study to his 1955 results. He noted that some high arctic species that had nested in the area in 1860 no longer did so, including several species of shorebirds that currently nest north of the Mackenzie Delta. Höhn related this change to the 'climatic improvement' believed to have taken place in the area, and stated that the treeline apparently crossed the Mackenzie Delta 25 km farther south in 1829 than in 1959.

Under current global climate change scenarios, with the expected decline in shallow wetland habitat in the outer delta, I would anticipate a decline in shorebird numbers in the delta for the most common and most aquatic species, the Red-necked Phalarope. I would expect it to extend its range farther north into the arctic islands, withdrawing from drier delta habitats. Numbers of Common Snipe will likely increase due to an expansion of dense willow habitat. Semipalmated Sandpiper and Lesser Golden Plover populations may also increase slightly in this area, with the expected increase in drier habitats. Numbers of other species are expected to remain fairly constant.

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Influences of Climatic Conditions in the Mackenzie Basin on the Success of Northern-Nesting Geese

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Abstract

The breeding success of four species of Arctic-nesting geese that breed in the north of the Mackenzie Basin, or stop in it while on migration, is examined in relation to climatic conditions during 1971-1993. The breeding success of northern geese has to be estimated indirectly, by field observations on goose flocks in autumn and by identifying young among the tails of geese contributed each year by hunters to the National Harvest Surveys (NHS) in Canada and the USA. Discriminant Function Analysis shows that breeding success is associated with monthly and seasonal variations in temperature and precipitation in two climate regions covering the MBIS area. Above normal precipitation in spring and summer, and above normal temperature in summer, in the Northwest Forest climate region are found to be favourable for geese. Above normal temperature in May and below normal precipitation in June in the Mackenzie District are also favourable conditions. Future changes in climate in the Mackenzie Basin are more likely to be detrimental than beneficial to geese, due to a northward shift of the treeline, delayed expansion of the tundra regions, and destabilization of permafrost and vegetation in the geese feeding areas.

1. Introduction

It has long been known that geese and other birds that breed in northern regions are affected by weather and climatic conditions (Elkins, 1988; Brooke and Birkhead, 1991). Cold spring and summer in the Arctic could disrupt bird migration and may cause breeding failure and many bird deaths (Boyd, 1992). On the other hand, early and fast snowmelt provides ample space for nesting and better conditions for vegetation growth. In an earlier study (Maarouf, 1994), it was suggested that warmer springs in recent decades in the MBIS area may have contributed to improved conditions for staging, nesting and breeding of geese in that region. In this paper, we expand on the previous work and provide the goose data used in the analysis.

There are no insuperable technical difficulties in tracking over time the performance of migratory geese while they are occupying large geographical areas, such as the Mackenzie Basin, by estimating their abundance, mortality and recruitment, but to do so would cost far more than any society is likely to think justified. The methods and levels of sampling that have been affordable have yielded data that are far less reliable than those of other environmental records, such as station records of temperature and precipitation, lake levels and stream flows, or catches of fish or animals of greater economic value. Consequently, it is not possible to carry out rigorous analyses of the effects of climate variation on geese. At best, only weak inferences are possible. Yet these have some value in several contexts. Here we attempt to identify how variations in seasonal climatic conditions over the Mackenzie Basin Impact Study (MBIS) area since 1971 have affected the abundance and breeding success of four species of geese that nest in large, and increasing, numbers in the northern parts of the Basin and in adjacent areas of the Arctic. We also speculate on the possible impacts of future climate change in the Basin on migratory geese.

2. Geese Data

The only comparable long-term regional records of geese are those obtained during aerial line-transect surveys carried out annually in late May. Those surveys are primarily intended to provide indices of the abundance of ducks; reporting of Canada geese has been incidental and sporadic, and the areas sampled do not extend into the mainland breeding areas of other species of geese. Thus it is necessary to rely on information obtained further south in autumn. The national harvest surveys (NHS) provide estimates of the numbers of geese shot, by province and zone in Canada, and by flyway and state in the USA. The species composition surveys (SCS) ask samples of hunters to send in the tails of the geese they have killed to be looked at by experts who can identify the species and tell which came from geese hatched in the previous summer and which from older birds. That information allows the total kill to be allocated by species and the percentage of young of each species to be estimated. The American NHS uses a different method of selecting hunters, but is otherwise similar to the Canadian survey. The survey results are of roughly similar reliability. The numbers of waterfowl hunters in

the USA are much larger, but the numbers of geese killed in the two countries differ much less. Substantial numbers of geese from the western Canadian Arctic winter in Mexico but there are no long runs of records of their numbers and breeding success.

In order to use the national harvest surveys as indicators of goose numbers and breeding success in the Mackenzie basin and the adjacent breeding areas it is necessary to set some very crude limits around the areas in western Canada and the western USA where most of them occur on passage in autumn or in winter. In Canada, we have used the entire provinces of Alberta and Saskatchewan as the sampling area, though some eastern Arctic geese occur there, and some western geese move through Manitoba, while others may go directly to the USA. In the USA, the states of the Central Flyway, from Montana south to Texas, serve as the principal catchment area for geese from northwest Canada, though most Ross's geese go to California. Because the lesser snow geese and white-fronted geese in California include many from Alaska, it seems best not to include them in the samples used here. White-fronted geese found in Mississippi Flyway states must come from the western Canadian Arctic and so are included in the USA samples; but most lesser snow geese in that flyway originate from the eastern Arctic, so are omitted from the sample.

Thus there are three major weaknesses of the goose hunting data used here: a) they are obtained far from the breeding area; b) they are obtained in October–December, after the first stage of their autumn migration; and c) the samples of geese included some from other breeding areas and omit others that should be included.

The hunting samples include relatively large numbers of young geese because they tend to be easier to shoot than older, experienced ones. The percentages of young geese seen in flocks of geese in the field provide better estimates of the true proportion and it is also possible to observe brood-sizes, i.e. the numbers of young in family

Table 1. Percentages of young in annual samples of geese breeding in the western Canadian Arctic and Subarctic and SHOT in 1971–1993 in: (1) Canada (Alberta and Saskatchewan) and (2) western USA; and (3) percent young SEEN in southwest USA in winter. In the last column, each year is classified according to low (L), normal (N), or high (H) percentage of young geese in the pooled average.

[**Note:** Both the Canadian and American national samples of Ross's geese are so small that only the combined estimates are tabulated here. Young Canada geese cannot be distinguished reliably from adults by field observations. The Canadian harvest survey did not distinguish between Canada geese of different size groups until 1971; and they have not been separated in the American surveys.]

Species ➔	Lesser Snow Geese			White-fronted Geese			Ross's Geese		Small Canada Geese		
	shot	shot	seen	shot	shot	seen	shot	seen	shot	ANNUAL	
YEAR	Canada	USA	USA	Canada	USA	USA		USA	Canada	MEAN	CLASS
1971	36.6	35.4	17.2	50.9		34.4	35.7	13.7	49.7	34.2	N
72	26.1	32.4	9.7	52.7		28.4	26.2	0.4	33.8	26.2	L
73	65.7	61	37.8	60.1	53.8	42.8	76.2	45.1	69.6	56.9	H
74	23.6	36	17.6	37.7	32.5	32.6	50	13.7	48.5	32.5	N
75	67.4	60.4	44.6	60.2	55.6	41.9	77.3	41.5	71.6	57.8	H
76	61	44.5	18.1	51.3	58.3	21.2	45	20.3	53.9	41.5	N
77	45.3	57.4	32.8	47.8	55.4	38.1	72.2	38.5	49.7	48.6	H
78	29.7	24.3	7.5	48	43.5	8.9	4.5	4.1	33.6	22.7	L
79	24.3	69.5	36.3	54.9	52.8	33	60.6	21.6	60.9	46.0	N
1980	44.9	43.9	20.2	50.2	53.1	34	45	27.3	57.6	41.8	N
81	35.1	50.8	34.6	50.5	44.5	33.8	42.6	22.1	53	40.8	N
82	33.3	45.2	20.2	32.9	36.4	29.9	59.1	22.7	33.1	34.8	N
83	46.3	46.5	20.5	50.8	47.7	37.6	53.5	22.1	62.9	43.1	N
84	42.8	48	26.5	48.3	45.4	44.7	74.6	28.8	59	46.5	N
85	45.9	45.2	24.5	54	38.2	35.4	59.1	21.5	54.4	42.0	N
86	22.1	26.6	8.4	33.1	26.9	29.6	53.5	12.1	45.1	28.6	L
87	30.2	45.1	12.2	42.8	45.9	24.8	35.3	7.1	48.5	32.4	N
88	46.9	56.7	25.2	46.2	42.8	27.8	58.7	15.6	50.5	41.2	N
89	32.9	51.1	27.4	42.7	43.6	33.9	59.9	28.6	53.3	41.5	N
1990	38.2	40.8	20.1	36.5	40.9	27.8	63.2	14.1	46	36.4	N
91	30.8	44.7	17.7	34.7	41.5	29.6	53.8	18.1	40.9	34.6	N
92	29.5	13.3	3.7	23.1	24.3	20.8	53.1	8	39.1	23.9	L
93	57.8	51.9	22.8	51	44.4	32.5	69.2	20.2	52.8	44.7	N
MEAN	39.8	44.8	22.0	46.1	44.2	31.5	53.4	20.3	50.8	39.1	
MAX	67.4	69.5	44.6	60.2	58.3	44.7	77.3	45.1	71.6	57.8	
MIN	22.1	13.3	3.7	23.1	24.3	8.9	4.5	0.4	33.1	22.7	
Std. Dev.	13.3	12.9	10.4	9.3	9.1	7.9	17.1	11.3	10.4	9.2	

parties. Regrettably, systematic field observations from western Canada in early autumn are not available. The records used here are from southern states, and collected in November-December, just before or during the hunting season (**Table 1**).

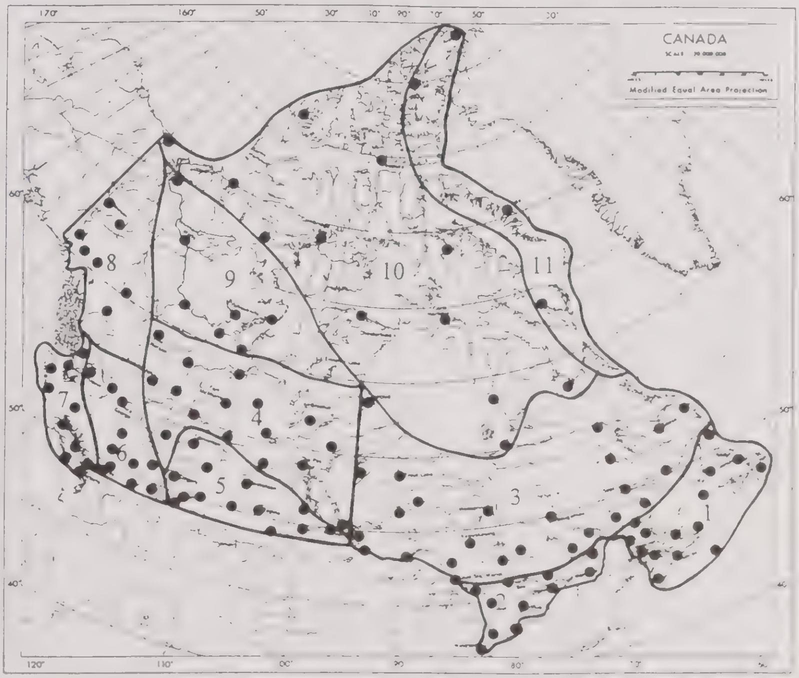
3. Climate Data

Temperature and precipitation are the only climatic variables for which there exist regional averages for the various climate regions in Canada. Several stations in each region (**Figure 1**) were employed in computing the regional average. Monthly and seasonal temperature and precipitation data were provided by the Climate Research Branch of the Atmospheric Environment Service (Environment Canada) in the form of departures from normal. Climatic normals are based on the period 1951-1980. The MBIS study area is contained within two climate regions (**Figure 1**): the Mackenzie District (region 9) and the Northwestern Forest (region 4). Region 4 covers also a large area of the prairie provinces which serve as a flyway for geese in spring and autumn. Monthly (April to September) and seasonal (spring, summer and autumn) temperature and precipitation data for climate regions 4 and 9 were used in this study. Spring is considered as the average of March, April and May; summer as the average of June, July and August; and autumn as the average of September, October and November. The period examined in this study consists of 23 years (1971-1993).

4. Method and Results

It is evident from **Table 1** that the percentage of young geese in the annual samples is highly variable from year to year, and also between species. As a first step in the analysis, observations for all four species were pooled to generate an average percentage of young for each year. The years were then classified as normal (N) if the percentage of young fell within one standard deviation (9.2) of the mean (39.1). They were classified as high (H) or low (L) if the percentage of young fell greater than one standard deviation above or below the mean, respectively, as shown in the last column of **Table 1**.

The multivariate statistical approach "Discriminant Function Analysis" (StatSoft, 1995) is used to determine which climate variables (independent variables) discriminate between the three (*a priori* defined) groups of H, N and L years of observations. The list of independent variables consists of 6 months (April to September) and 3 seasons (spring, summer and autumn) of temperature and precipitation data expressed as departures from normal for the two climate regions 4 (Northwestern Forest) and 9 (Mackenzie District). Thus, a total of 36 independent variables were applied to the discriminant function analysis to build a model of discrimination using a forward step-by-step mode (StatSoft, 1995). The process of independent variable selection terminates when no more variables are found to contribute significantly to the discriminant func-



1. Atlantic Canada
2. Great Lakes Basin / St. Lawrence Lowlands
3. Northeastern Forest
4. Northwestern Forest
5. Prairies
6. South British Columbia Mountains
7. Pacific Coast
8. Yukon / North British Columbia Mountains
9. Mackenzie District
10. Arctic Tundra
11. Arctic Mountains and Fiords

Figure 1. The various climate regions and climate recording stations associated with the historical Canadian climate database.

tions.

In this analysis of three groups of geese-years, the method provides two discriminant functions. The first function provides the greatest overall discrimination between groups. The two functions are independent or orthogonal, i.e. their contributions to the discrimination between groups do not overlap. **Table 2** shows the means for the first and second discriminant function (Root 1 and Root 2, respectively). The first function seems to discriminate very well between all three groups. The second function discriminates between the high and low groups together (both show positive and nearly equal means), and the normal group (a negative mean). In order to visualize how these two functions discriminate between groups, the individual scores for the two discriminant functions are plotted in **Figure 2**. Again, function 1 (Root 1), seems to discriminate well between all three groups. In the vertical direction (Root 2) most of the normal group data fall below the zero line, while the low and high groups all lie above the zero line.

Table 2. Means for the first and second discriminant functions (Root 1 and Root 2)

Statistical Discriminant Analysis	Means of Canonical Variables	
Group	Root 1	Root 2
N	-0.014	-0.690
L	3.330	1.560
H	-4.370	1.600

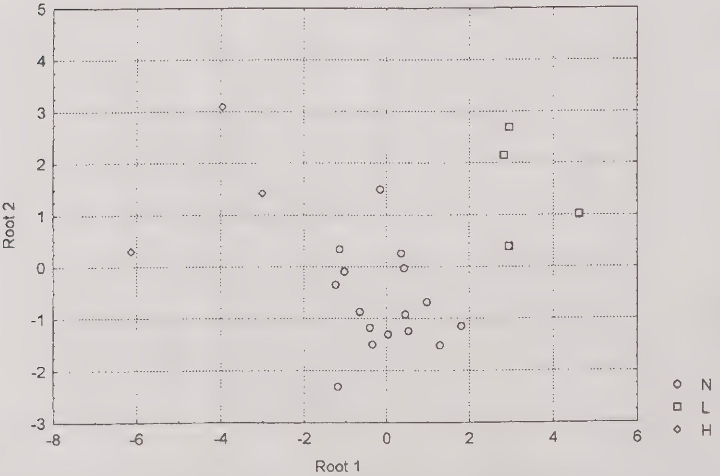


Figure 2. Plot of the individual scores for the two discriminant functions.

Table 3 shows the selected independent (climate) variables and their standardized coefficients, i.e. their contributions to the discriminant functions, which may be compared in order to determine the magnitudes and directions of the unique contributions of the variables to each discriminant function. Also shown in the table are the eigenvalues (roots) for each discriminant function and the cumulative proportion of explained variance accounted for by each function. It is seen that the first function accounts for over 80% of the explained variance; i.e. 80% of all discriminatory power is explained by this function. Thus, this first function is clearly the most important one, and we will focus discussion on its coefficients.

The climate variables which have the largest coefficients (**Table 3**) are summer precipitation in region 4 (coefficient -1.8), May precipitation in region 4 (coefficient -1.7), and June precipitation in region 9 (coefficient +1.4). From **Figure 2**, it is evident that the first discriminant function (Root 1) has negative scores (< -2) for the H class (high percentage of young geese in the sample), and positive scores (> +2) associated with the L class (low percentage of young geese). This suggests that above normal

Table 3. The climate variables selected by the discriminant function analysis and their coefficients for the first and second discriminant functions (Root 1 and Root 2). Variables start with T (temperature) or P (precipitation), followed by three letters of the month/season, followed by 4 (Northwestern Forest) or 9 (Mackenzie District).

Also shown are the eigenvalues (roots) for each discriminant function and the cumulative proportion of explained variance accounted for by each function.

Statistical Discriminant Analysis	Standardized Coefficients for Canonical Variables	
Variable	Root 1	Root 2
PSUM_4	-1.83	0.01
PMAY_4	-1.72	0.66
PJUN_9	1.4	0.08
PAPR_9	-0.9	0.91
TMAY_9	-0.86	0.37
TJUL_4	-0.84	-0.21
PAPR_4	-0.83	0.35
PAUT_9	-0.81	-0.82
Eigenvalue	5.08	1.25
Cumulative proportion	0.802	1.0

precipitation in May and summer in region 4 and below normal precipitation in June in region 9 would contribute significantly to the abundance of young geese. Since geese use much of region 4 as a flyway in their southward return migration in autumn, increasing precipitation in spring and summer is considered favourable for vegetation growth and productive wetlands and shallow meadows. On the other hand, below normal precipitation in June in the Mackenzie District could be associated with more sunshine and faster snowmelt, allowing better nesting conditions for geese.

The remaining set of selected climate variables include, in decreasing order of coefficients, April precipitation in region 9, May temperature in region 9, July temperature in region 4, April precipitation in region 4, and autumn precipitation in region 9 (**Table 3**). Their contributions to the first discriminant function are much less than the three variables discussed above. They all have negative coefficients, which suggests that above normal values of these variables would be associated with higher than normal percentages of young geese in the samples.

5. Discussion

From the above analysis, one could infer that during the period 1971-1993, increased production of young geese within the MBIS region was associated with above normal spring and summer precipitation in region 4 (Northwestern Forest) as well as above normal July temperature, which indicate favourable conditions for plant growth. Region 9 (Mackenzie District), on the other hand, was associated mainly with below normal precipitation in June and above normal May temperature; both variables are indicators of early snowmelt and favourable conditions for nesting and breeding success.

A recent study of the state of Canada's climate (Environment Canada, 1995) indicates that over the period 1895-1992 the greatest warming occurred in the Mackenzie District (1.7°C), followed by the Northwestern Forest (1.4°C). Seasonal variations were also observed with the greatest warming occurring in the spring (2.4°C in the Mackenzie, and 2.1°C in the Northwestern Forest), followed by winter, summer and autumn, respectively. The annual average increase in the daily minimum temperature was higher (1.9°C in Mackenzie; 2.1°C in Northwestern Forest) than the increase in the daily maximum temperature (1.3°C in Mackenzie; 0.5°C in Northwestern Forest). These temperature trends could have contributed, in recent decades, to more favourable conditions for spring migration of geese, as well as early snowmelt, less frequent frost occurrences, and longer summer conditions in the MBIS region. Regional annual precipitation data show no change in trend in the Northwestern Forest, and only a slightly increasing trend in the Mackenzie, over a shorter period of records (1948-1992).

Further climatic changes for the MBIS region, as projected by recent GCMs, indicate that this region would warm by 4 to 5°C by 2050 (Cohen, 1994, 1996). The warming, however, will be greater in winter than in summer. Obviously, other variables will not remain constant (Hengeveld, 1995). A northward shift of the treeline, increased permafrost thaw and accompanying landslides, and changes in the active layer above the permafrost may destabilize the vegetation of the wet meadows which are the most important feeding areas for geese. Other changes include decreased areas of Arctic tundra where many migratory birds and other species breed, leading to overcrowding and more competition. Higher temperatures will significantly increase the rate at which vegetation and soils lose water to the atmosphere, thus reducing available soil moisture. Other stresses may result from increased frequency and severity of forest fires, increased ultraviolet radiation, and increased pollution levels in the northern environment. We therefore speculate that the projected future changes in climatic and environmental conditions are more likely to be detrimental than beneficial to geese.

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7

PEOPLE: ECONOMIC ACTIVITIES AND COMMUNITIES

Coping with Floods: An Analogue for Dealing with the Transition to a Modified Climate in the Northern Sector of the Mackenzie Basin

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Abstract

Habitation north of the 60th latitude in the Mackenzie Basin is primarily found in small, relatively isolated communities whose population and governing bodies are largely aboriginal. The settled pattern of community life has come only recently to the Dene and Inuit people, who retain a strong attachment to land-based activities which form an integral part of their respective cultures. To cope with the inevitable episodes of flooding, these people draw on their knowledge of natural systems and experience with previous floods. Today, these traditional skills are complemented by modern technologies and an extensive external support structure. Investigations in the communities of Aklavik and Fort Liard, N.W.T. address coping at the individual, communal and governmental levels. The evolving system of survival reflects a unique convergence of skills and technologies which may provide fruitful analogues for coping with climate change and the resultant extremes. The findings stress the shifting nature of responsibilities between levels and, with the growing complexity of communities, dependence on a diversity of knowledge. The crucial question of transition is raised as successful coping mechanisms are seen to evolve from repeated application over generational time frames. In conclusion, capability to adapt to an increased variability in climatic extremes in northern communities must be placed in the context of other critical threats seen to emanate from social, cultural and political spheres.

Introduction

Impressions of the north, its landscape and people are largely drawn from public images, not personal experience, making misconceptions commonplace. This research has been designed to improve our understanding of how remote communities in Canada's North cope with natural hazards, such as flooding. Second, the exploration of flooding can provide an analogue of how citizens and governments might deal with suggested manifestations of regional climate change. Acknowledging the complex integration of traditional knowledge (Bielawski 1992; 1994; Johnson 1992; Legat 1991) and modern technologies is considered essential to gain a better appreciation of coping mechanisms. Moreover, evidence obtained from studying the response of residents to extreme episodes of flooding is thought to be crucial to understanding the sustainability of settlements (Mileti et al. 1995). Central to the research design are distinctions between perceptions, attitudes, and activities at three operational levels - individual; communal; governmental - and an appreciation of how these levels interrelate in response to emergencies such as flooding (Newton 1994:422).

Only through a research design sensitive to cultural, social, political, economic and physical influences can the research themes of coping, preparedness and external involvement be successfully addressed (Newton 1993:86-96). Based on fieldwork in Aklavik and Fort Liard, Newton (1994) has elaborated on the research findings and implications for isolated communities in the Mackenzie Basin. In this paper the research is summarized and extended to explore the process of coping with the transition to modified climatic norms for small, remote communities. Nonetheless, important questions remain to be asked about the implications of climate change for inhabitants of the Mackenzie Basin, not in 2020 but during the transition to two or three times current levels of atmospheric CO_2. How will people adapt to incremental changes? Will historical coping mechanisms prove adequate? And what can be done today to mitigate potential negative impacts? It is apparent that how people cope with floods could be an analogue for how they will deal with changes in climate.

The Research Context

We now accept that natural disasters result from the interaction of natural and human systems at regional, national, and global scales. Moreover, the physical surroundings, historic events, social conditions, and the political and economic decisions shaping the North today, all contribute to the context within which people cope with abnormalities. Indeed, flooding hazards, preparatory actions, and disaster responses can not meaningfully be considered *apart from these surrounding influences.*

If one accepts that isolated northern communities, and other similar settlements worldwide, are in transition from a traditional land-based economy to a wage economy

incorporating many characteristics of a modern society (Smith 1973), then how has this change influenced their ability to cope with natural hazards? Have traditional coping mechanisms been eroded or augmented by the influence of modern society? And how will these changes influence the ability to cope with increased climatic variability? These questions demand contextual thinking.

Research in aboriginal communities is based on conversation and observation. Listening becomes the primary research method. Only through a concerted effort to hear the messages offered by local voices can information be obtained and observations clarified. This investigation of coping with flood hazards depends on local insights and the melding of modern and aboriginal science.

Primary Observations

Adaptation to episodes of flooding in remote communities is a multifaceted issue. Beyond high water levels and the resultant damage lies the socio-economic characteristics of the community, its history, and degree of integration with the outside world. Furthermore, physical conditions and climatic cycles are contributors. Taken together the aspects influencing adaptation to flooding touch on virtually all areas of life in a community. The issue is not singular, but multiple, drawing human and natural processes into dynamic relationship.

Coping with floods in northern communities, as with hazards anywhere, follows an almost universal sequence of stages: (1) perception of risk; (2) emergency preparedness; (3) local response; and, (4) recovery. Individuals may not always be acutely aware of each stage, however each *must occur* in sequential order. This research focuses on the first three stages. For the purposes of the Mackenzie Basin Impact Study the primary findings of this research have been presented under three headings: (A) Perception; (B) Preparedness; and, (C) Response (Newton 1994:423-426).

Table 1: Level of reference to hydro/climatic signs which respondents believe signal potential flooding.

Hydro/Climatic Factors	Response (%) Aklavik	Response (%) Fort Liard
1. Ice thickness	66	32
2. Weather condition during freeze-up	34	35
3. Depth of snow	32	58
4. Climatic conditions prior to break-up	37	39
5. Ice conditions in the spring	32	13
6. Ice jamming	74	26

A brief summary of each area is provided here as a backdrop for secondary observations.

(A) Perception

Observing the signs and signals of nature is part of daily life. Such understanding guides actions and builds resilience to shifts and changes in the environment. These perceptions represent an inherent system of survival accurately attuned through generations of experience in a specific territory. Through probing to identify signs in the study communities, six hydro/climatic factors thought to influence the occurrence of flooding were commonly referred to by respondents. In **Table 1** the frequency of response is noted as a percentage of the total interviews in each community.

Awareness of these signs and conditions is essential to understanding flooding, not just as a physical event, but as an infrequent, though integral part of life in northern communities such as Aklavik and Liard.

(B) Preparedness

There no longer exists the question of *whether* people prepare for break-up and the flooding they know can occur, but rather *how* they prepare. Six factors influence preparedness for flooding (**Table 2**). People at each operational level will prepare differently, and respond differently to the

Table 2: Influence of factors on emergency preparedness for flooding in Aklavik and Fort Liard at the individual, community and government operational levels. Scale of influence used is - Strong; Moderate; Minor; Minimal; None; Uncertain.

Influencing Factor	Individual		Community		Government	
	Aklavik	Liard	Aklavik	Liard	Aklavik	Liard
i) Warnings and Notices	Minimal	Minor	Minor	Minor	Minor	Minimal
ii) Past Experience	Strong	Strong	Minimal	Moderate	Minimal	Minimal
iii) Time since last episode of flooding	Minor	Strong	Minimal	Strong	Minimal	Minimal
iv) Actions and Opinions of Others	Moderate	Minor	Minor	Minimal	Strong	Strong
v) Weather, Water and Ice Conditions	Strong	Strong	Moderate	Moderate	Moderate	Moderate
vi) Frequency of Flooding	Minimal	Uncertain	None	Uncertain	Strong	Strong

formal and informal messages and signals they receive.

The assignment of ratings is subjective, based upon interviews, conversations and observations as actual episodes of flooding developed. Differences between Aklavik and Liard reflect their respective community flood history, social structure and physical setting.

Of note in **Table 2** is the near universal value assigned to natural conditions (Factor v) as precursors of flooding. Appreciating differences in perception can help to explain inconsistencies in preparedness and preparatory activities. Understanding what factors motivate activity can give clarity and coherence to otherwise confusing behaviour, providing greater comprehension and reducing inter-level conflict.

Table 3: Comparison of response activities in Aklavik and Fort Liard at three operational levels.

		Operational Level					
		Individual		Community		Government	
No.	Response Activities	AK	FL	AK	FL	AK	FL
1.	Move belongings to high ground	●	+	●	●	●	●
2.	Secure personal belongings	+	+	●	●	●	●
3.	Watch children	+	+	●	●	●	●
4.	Take an inventory of belongings	+	–	●	●	●	●
5.	Ensure adequate supply of food	+	–	–	–	●	●
6.	Have boats & canoes ready	+	–	+	–	●	●
7.	Conserve water	+	–	–	–	●	●
8.	Care for sick & elderly	+	+	+	+	+	–
9.	Monitor ice & water levels	+	+	+	+	+	+
10.	Broadcast information	+	–	+	+	+	+
11.	Supply additional resources	●	●	+	+	+	+
12.	Establish operations centre	●	●	+	+	+	–
13.	Establish evacuation procedures	●	●	+	+	+	–
14.	Organize reception services	●	●	+	+	+	–

Key: AK = Aklavik; FL = Fort Liard. + = Activity occurs; – = Activity does not occur; ● = Not an area of responsibility or possible action.

(C) Response

Response, whether individual, communal, or governmental, is an extension of preparedness activities, a continuation of the natural human coping mechanisms, aimed at safety and survival. **Table 3** notes the variation in coping actions in each of the two study communities at each operational level. Personal experience with the 1992 floods in Aklavik and Liard supports this summary of coping actions.

Moreover, the response to a disaster occurs first and foremost at the individual and local level, people responding to save themselves, each other and their belongings. For isolated communities the necessity of a community-wide response is amplified by the knowledge that additional assistance is not readily available, and when needed, may not arrive in time. In light of these logistical realities, small remote communities must be prepared to co-ordinate local resources for a timely response to flooding.

Of significance in **Table 3** is the transition from responsive activities which are primarily the responsibility of individuals, through those activities that are generally shared, to activities which require the resource base of communities and governments. This shifting of responsibility is representative of increases in individual, and eventually community, vulnerability. As more resource rich operational levels have become involved in disaster response they ideally complement local and individual initiatives. Minimizing losses is still the ultimate objective.

Presence or lack of an activity as noted in **Table 3** is not absolute, but indicative of the general level of each activity in Aklavik or Fort Liard. With the exception of item #4, the first nine individual response activities represent historic coping strategies used by mobile family groups. Community structures have since added depth, some co-ordination and support for weak segments of the population, to traditional coping mechanisms. More recently, where community vulnerability has increased, responsibilities have been shifted to governments, for assistance with more structured response procedures and plans.

Secondary Observations

Beyond the primary investigation of coping with floods in northern Canadian communities lies inferred capabilities for other environmental perturbations. What can the ability of individuals, communities, and governments to cope with floods tell us about their ability to cope with other variable or permanent changes? Can a better understanding of adaptation to floods be informative for future challenges due to climate change? This research did not set out to answer such questions. However, the essence of human-environment interaction which underlies the investigation of flooding may provide a useful analogue for consideration of the implications of climate change.

To begin, it is apparent that people do not 'deal with climate change' but rather with the various conditions thought to be brought on by climate change. Thinning of the ozone layer and changes in weather patterns garner the greatest attention, not the gradual changes in global averages. Consequently, attention must be redirected from end conditions, such as $2xCO_2$, to the transitional period and the increased variability of extreme natural episodes (i.e. torrential rains, earthquakes, droughts, etc.). Regardless of global protocols and national programs *people* will have to adapt. The consumption juggernaut we have created is unlikely to decline; in fact, with inevitable increases in global population it will undoubtedly gain momentum.

What does experience with flooding have to contribute to the climate change discussion? Perhaps the most valuable contribution is encouragement to augment long term prediction with attention to the capabilities of populations to adapt on an ongoing basis. The history of flooding in communities north of 60° would support a resilience population with strong levels of self-sufficiency due to well developed capabilities and an intuitive appreciation of natural systems. Yes, some individuals are vulnerable, but past experience with flooding would indicate that people in the isolated communities are well adapted to the current variability of the natural environment. If the nature of climatic extremes, *during a 20–30 year transition period,* are not far from present extremes citizens will draw on past experience and developed capabilities to cope. Adaptation will result from coping with repeated natural events which slowly shift today's norms. The experience with flooding in Aklavik would tend to support this thesis.

Belief that such an adaptive capability is present in urban centres, where there exists a greater dependence on response organizations and a reduced connectedness to natural systems, is ill-advised due to differences in perception, and thus action. Adaptation to climatic variability in urban centres cannot be ruled out, but will likely be individual and slow to evolve into community-level capabilities. With a fragmented perception of human-environment relationships much time will be taken up with denial, delaying the implementation of adaptation strategies and the development of resilience-building capabilities.

Table 4: Summary of research observations and findings.

No.	Research Observation or Finding	Comments and Notes
1.	Individuals are attentive to local conditions	Historically, survival depended on an accurate perception of environmental conditions. Such awareness persists today.
2.	Community structures now provide the framework for response	No longer do family groups function independently. They are part of, and thus depend on, the larger community, its leaders and governing bodies.
3.	Concentrated living can increase vulnerability to hazards	Permanent settlements increase the amount and value of belongings and structures, reducing ease of mobility.
4.	Changes in social structure will influence vulnerability	The evolution of dependent groups in established settlements requires response services beyond those traditionally available through family groups. Community and external agencies must now respond to ensure individual safety.
5.	As land based skills disappear resilience and self-reliance diminish	Response capability to flood hazards is shifting from individual skills to community, and when necessary, external mechanisms.
6.	As isolated communities grow the complexity of response increases	High birth rates, changing social structures, the shift from land-based knowledge to school systems, and in-migration create larger more complex communities subject to internal turmoil. Coping with emergencies in isolated aboriginal communities requires an appreciation of these evolving social conditions.
7.	Water alone will rarely cause flooding. Ice jams must occur.	Most rivers are large and under free-flow conditions are able to carry the peak discharge. Ice jams cause water to back up and when failure occurs can create devastating localized peaks.
8.	Flooding is a function of a number of concurrent conditions	More than two of the factors listed in Table 1 must occur concurrently during the spring for a serious flood hazard to exist.
9.	Adjustment to climate change will be gradual	Where people are attentive to their physical environment small adjustments are constantly taking place as part of daily life. If climate change in the Basin occurs over 40-100 years people will adjust gradually with the slight annual shifts.
10.	Northern communities face more critical threats than flooding	Today, the future of northern communities is threatened by changes in social structure, economic conditions, western culture and political policy.

As interconnections between human and natural systems become broadly accepted, linkages between research activities and citizens improve, and local capabilities receive greater attention, coping with floods and other climate induced perturbations will gradually become an integral part of everyday life. Not something to be feared, but episodes that are excepted and understood, and thus dealt with efficiently and with minimum disruption.

Conclusion

Living close to the land, and consequently understanding and respecting the perturbations of the natural environment, gives most residents of small isolated communities an inherent resilience to natural occurrences of flooding. Natural hazards are part of normal life. Unfortunately, community living can act counter to this inherent capability, by reducing resilience and increasing vulnerability. The degree to which land-based people accept Euro-Canadian norms of community living and allow their land related skills and knowledge to diminish will feed these counteracting forces (Ohmagari 1994). Moreover, a dependency can develop, where residents begin to look to external sources for assistance rather than taking individual and communal action. A summary of research observations and findings are presented in **Table 4**, together with explanatory comments and notes which illuminate the underlying influences.

Whether potential climate change will affect the vulnerability of isolated communities in the Mackenzie Basin is questionable (Aharonian 1994). Slight overall changes in run-off (Soulis et al. 1994) are unlikely to be of significance as damaging floods in Aklavik and Fort Liard results from ice jams.

The shift from the dominance of bush knowledge to dependence on Euro-Canadian education systems, combined with the decline in the traditional land-based economy and the rise of wage-based economies, and the related emphasis on material wealth require a rapid adjustment and shift in values by northern residents. Moreover, the consensus orientation of decision-making is being supplanted by a confrontational style diluting the cohesive social structure which has historically been central to the survival of northern people living under harsh conditions. These factors will likely be more immediately critical to the vulnerability of isolated northern communities than the influence of long term shifts in regional climate patterns (extremes notwithstanding).

A cursory glance at the range of possible factors influencing the sustainability of northern communities would seem to indicate that residents can cope with gradual changes to the natural environment better than direct human-induced perturbations. To understand the implications of climate change for residents and businesses in the Mackenzie Basin attention must be directed to the ongoing transitional period. This research's focus on coping with floods indicates the capacity of residents to adapt and might provide a helpful analogue for the likelihood of adaptation to future changes in the regional climate.

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The Socio-Economic Implications of Climate Change in the Forest Sector of the Mackenzie Basin

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Abstract

Forests play a significant role in the Mackenzie Basin, both in ecological and socio-economic systems. They provide numerous services to society: jobs, income, recreation, environmental services (e.g. carbon sequestration and habitat for valued species), and spiritual services. To date, very little work has examined the social and economic impacts resulting from the biophysical impacts of climate change on forests, and what research exists has focused on basic economic parameters (prices, harvests, supply, consumer surplus) at broad regional or national scales, generally using regional trade models. In this study, we examine the current role of forests and existing policies related to their long-term use.

Using results from Hartley, Kadonaga, and Sieben, in conjunction with work on the current and future roles of forests and forest management, we find that the impacts of climate change will depend upon numerous factors. The changing structure of the forest, i.e. species mix, productivity, and land cover, are influenced as much by secondary effects of changing climate - fire incidence and pest infestation - as by changes in temperature and precipitation. In turn, the ultimate impacts on social and economic systems - harvest levels, recreational opportunities, employment, governmental revenues and expenditures, community stability, etc. - must be understood in the context of land use designation policies, fire and insect control policies, technology development and utilization, trade policies, and many other concurrent developments, only some of which are directly related to changing climate. Given the size of the potential biophysical and socio-economic impacts seen and the time horizons over which policies related to forests must be considered, it is important that changing climate be considered in evaluating existing and future policies.

Forests and the Forest Sector within the Mackenzie River Basin

Forests play a significant role in the Mackenzie Basin, both in ecological and socio-economic systems. They provide numerous services to society: jobs, income, recreation, environmental services (e.g. carbon sequestration and habitat for valued species), and spiritual services. To date, very little work has examined the social and economic impacts resulting from the biophysical effects of climate change on forests, and what research exists has focused on basic economic parameters (prices, harvests, supply, consumer welfare) at broad regional or national scales (Binkley and van Kooten 1994; Sohngen and Mendelsohn 1995; Sohngen, Sedjo et al. 1996). In this study, we examine the current role of forests and existing policies related to their long-term use and how these might be affected by changing climate. With recognition of its limited scope, this analysis will focus upon the commercial forest sector. As such, it will emphasize the southern portion of the Mackenzie River Basin, in general, and British Columbia in particular.

The forest sector, including the logging and silviculture, wood products, and paper and allied products industries, makes a significant contribution to the economies of the provinces and territories which encompass the Mackenzie River Basin. Within the Basin the principal commercial forestry activity is in British Columbia and, increasingly in recent years, Alberta. The forest sector accounts for about 8 percent of provincial Gross Domestic Product (GDP) in BC and just over 1 percent in Alberta

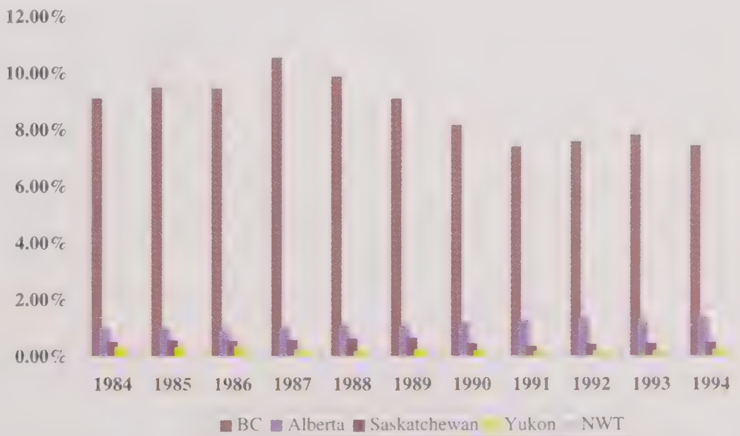

Figure 1. Forest sector share in total economy (GDP at factor cost, 1986 constant dollars.)

(see Figure 1). As can be seen in Figure 2, volumes harvested are largest by far in BC, with an annual harvest of over 75 million cubic meters. Harvests in Alberta have been increasing in recent years; in 1993 nearly 20 million cubic meters were harvested there. Harvests elsewhere in the basin have remained small and relatively flat. Within the parts of BC that lie in the Mackenzie Basin, volumes harvested are largest in the Prince George Forest District and smallest in the Cassiar Forest District (see Figure 3).

Most of the commercial forest land in Alberta and the larger part of the Prince George Forest Region of British Columbia fall within the Basin. There are significant amounts of mature timber in the region, but also large amounts of immature timber (see Figure 4). Most of the productive forest land is under provincial or territorial control (see Figure 5).

The importance of the forest sector is magnified in specific locales. Twelve communities in or near the Mackenzie River Basin have been identified as being significantly dependent upon the forest sector for their local employment and/or earnings (see Table 1) (Bone and Long 1995; Williamson and Annaraj 1995). A study looking at the forest districts within British Columbia shows that the forest sector represents a significant share of the base economies of all of the forest districts within the Mackenzie Basin, accounting for as much as 70% of local employment (see Table 2 and Figure 6) (Horne and Powell 1995b).

These data include not only direct employment and earnings but also indirect (suppliers of materials and services to the forest-based industries) and induced or non-basic (induced by spending of forest-based employees in the local economy) employment and earnings. Estimates of local and provincial employment and earnings, as well as provincial and federal revenues, associated with each 1000 cubic meters of timber harvested are shown

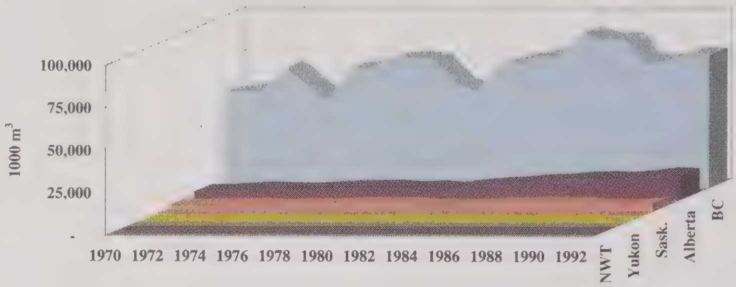

Figure 2. Volume harvested by province and territory.

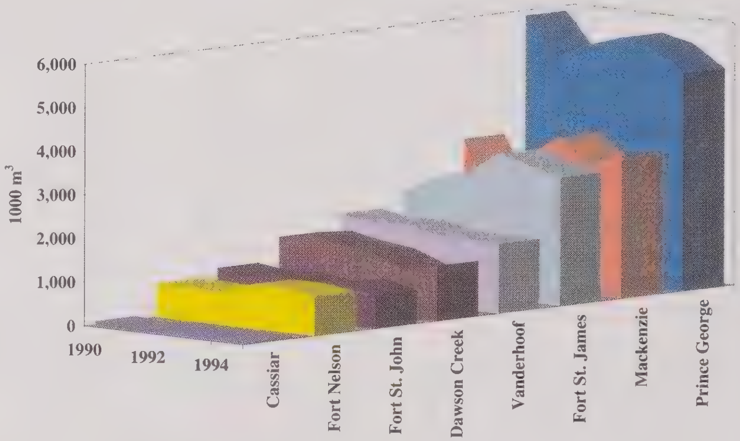

Figure 3. Volume harvested by BC Forest District.

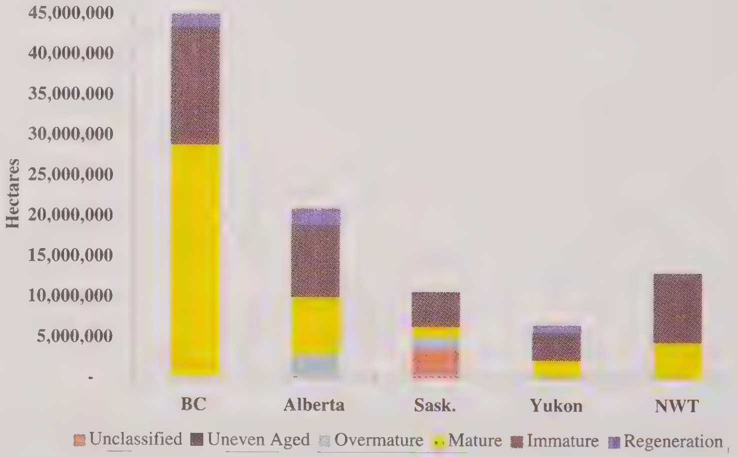

Figure 4. Stocked non-reserved timber productive forest land.

in **Table 3** (ARA Consulting Group Inc. 1993; ARA Consulting Group Inc. 1995; Bull and Williams 1995; Bull and Williams 1996). The effect of a unit of harvest differs significantly between TSAs, particularly in their impact on the local economy. This reflects differences in the structure of the industry, those areas with more secondary processing receiving more economic benefits per unit of harvest.

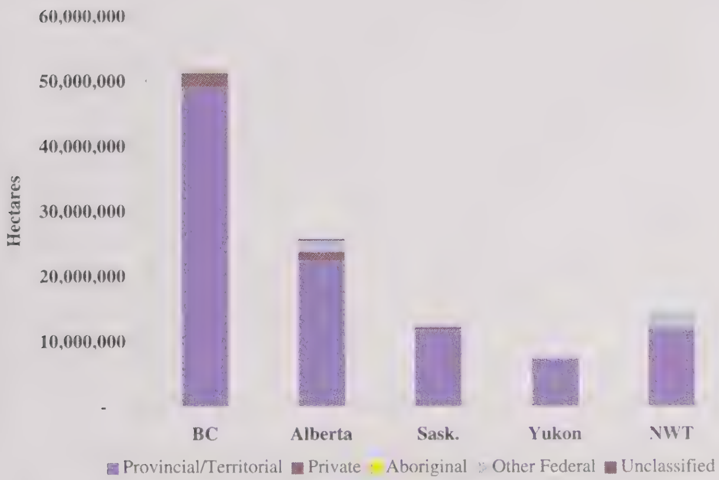

Figure 5. Timber productive forest land ownership.

Forest Dependent Communities identified by Bone and Long (1995)	
Community	**1991 Population**
Taylor, BC	821
Hudson Hope, BC	985
Chetwynd, BC	2,843
Mackenzie, BC	5,796
Whitecourt, Alta	6,938
Barrhead, Alta	4,160
Edson, Alta	7,323
Hinton, Alta	9,046

Forest Dependent Communities identified by Williamson and Annaraj (1995)	
Community	**1991 Population**
Mackenzie, BC	5,796
Fort St. James, BC	2,058
Vanderhoof, BC*	4,023
Prince George, BC*	69,653
Whitecourt, Alta	6,938
Hinton, Alta	9,046
Mayerthorpe, Alta	1,692

* The communities of Prince George and Vanderhoof fall outside of the Mackenzie Basin, but are important centers within the Prince George Timber Supply Area

Table 1. Forest dependent communities.

The Impact of Changing Climate on Forests

The principle biophysical impacts of changing climate on forests have been explored by Hartley, Kadonaga, and Sieben as part of the Mackenzie Basin Impact Study. This section will briefly discuss some of their results. The reader is referred to their studies, presented in this volume, for further details on these topics. It is important to recognize that the following results represent only a single possible scenario, with large degrees of uncertainty on the scientific side and, perhaps more importantly, do not incorporate any changes in the management of forests by people in the region.

A few particulars stand out. First, whereas the potential productivity of younger trees is increased by changing climate, older trees do not fare as well (see **Figure 7**). Secondly, the deciduous species appear to fare better in terms of potential growth than do the coniferous (see **Figure 7**). Perhaps most striking is the degree to which the area burnt in forest fires increases with the changing climate, an increase of two and a half times by 2050 (see **Figure 8**). This and the inability of older, mature and overmature, trees to adapt to the changing climate combine to cause a shift toward younger ages and an overall significant decline in standing volume (see **Figures 8 and 10**). Also, the increase in deciduous species represented by their potential growth is not really borne out at the Basin level, as shown in **Figure 9**.

The overall changes described above are fairly consistent across the Basin, but there is significant local variation. Some of this can be seen by looking at the results for individual Timber Supply Areas (TSAs) within British Columbia (see **Figures 11–17**). In particular, the timing and magnitude of the changes in total volume, average age and area burnt by fire differ geographically (see **Figure 11**). There is a general correlation between earlier onsets and more southern latitudes. As can be seen in the top panel of **Figure 11**, total volume begins immediately to decline in the Mackenzie, Prince George and Daw-

Table 2. British Columbia Forest District dependencies.

		EMPLOYMENT					AFTER TAX INCOME ($MILLION)				
Forest District	**Sector**	**Direct**	**Indirect**	**NonBasic**	**Total**	**Share of TSA Total**	**Direct**	**Indirect**	**NonBasic**	**Total**	**Share of TSA Total**
Cassiar	*Logging*	62	9	7	78	6%	1.6	0.2	0.1	1.9	6%
	Other Wood Manufacturing	12	2	1	15	1%	0.3	0	0	0.3	1%
	Pulp&Paper	0	0	0	0	0%	0	0	0	0	0%
	Total	**74**	**11**	**8**	**93**	**7%**	**1.9**	**0.2**	**0.1**	**2.2**	**7%**
Dawson Creek	*Logging*	407	92	136	635	5%	11.3	2.1	2.4	15.8	4%
	Other Wood Manufacturing	602	94	176	872	6%	15.4	1.9	3.1	20.4	6%
	Pulp&Paper	180	58	69	307	2%	5.6	1.3	1.2	8.1	2%
	Total	**1189**	**244**	**381**	**1814**	**13%**	**32.3**	**5.3**	**6.7**	**44.3**	**12%**
Fort Nelson	*Logging*	28	6	8	42	2%	0.7	0.1	0.1	0.9	2%
	Other Wood Manufacturing	498	92	129	719	30%	12.1	1.8	2.3	16.2	27%
	Pulp&Paper	0	0	0	0	0%	0	0	0	0	0%
	Total	**526**	**98**	**137**	**761**	**31%**	**12.8**	**1.9**	**2.4**	**17.1**	**29%**
Fort St. James	*Logging*	122	40	31	193	13%	3.4	0.7	0.5	4.6	12%
	Other Wood Manufacturing	365	15	71	451	31%	9.1	0.3	1.3	10.7	27%
	Pulp&Paper	0	0	0	0	0%	0	0	0	0	0%
	Total	**487**	**55**	**102**	**644**	**45%**	**12.5**	**1**	**1.8**	**15.3**	**39%**
Fort St. John	*Logging*	251	59	102	412	3%	7	1.3	1.8	10.1	3%
	Other Wood Manufacturing	269	34	91	394	3%	6.8	0.7	1.6	9.1	3%
	Pulp&Paper	104	34	47	185	2%	3.2	0.7	0.8	4.7	2%
	Total	**624**	**127**	**240**	**991**	**8%**	**17**	**2.7**	**4.2**	**23.9**	**8%**
Mackenzie	*Logging*	199	45	57	301	10%	6.3	1.2	1.1	8.6	9%
	Other Wood Manufacturing	748	62	179	989	33%	22.1	1.5	3.4	27	29%
	Pulp&Paper	544	121	169	834	28%	19.4	2.9	3.2	25.5	27%
	Total	**1491**	**228**	**405**	**2124**	**71%**	**47.8**	**5.6**	**7.7**	**61.1**	**65%**
Prince George	*Logging*	2177	1198	1011	4386	11%	63.1	25.5	18.5	107	10%
	Other Wood Manufacturing	2771	1041	1085	4897	13%	74.5	20.7	19.9	115	10%
	Pulp&Paper	1613	801	786	3200	8%	51.9	17.1	14.4	83.4	8%
	Total	**6561**	**3040**	**2882**	**12483**	**32%**	**189.5**	**63.3**	**52.8**	**306**	**28%**
Vanderhoof	*Logging*	377	175	109	661	15%	10.4	3.3	1.9	15.6	13%
	Other Wood Manufacturing	811	69	177	1057	23%	20.6	1.5	3.1	25.2	21%
	Pulp&Paper	0	0	0	0	0%	0	0	0	0	0%
	Total	**1188**	**244**	**286**	**1718**	**38%**	**31**	**4.8**	**5**	**40.8**	**33%**

son Creek TSAs, while volumes do not begin to decline in the other TSAs until 2010 or later. A similar pattern holds for average age (see bottom left panel of **Figure 11**). This reflects the much greater areas burnt in the more southerly TSAs and also the loss of older trees, which are unable to adapt to the changing climatic conditions (see bottom right panel of **Figure 11**).

The initial breakdowns of species volume percentage and shifts in these over time also differ markedly between parts of the Basin (see **Figures 12-17**). Some of the shifts in the models results reflect processes other than climate change incorporated in Hartley's model (which are represented in the left panels of **Figures 12-17**), but the shifts are much more dramatic in the presence of changing climate (represented in the right panels of **Figures 12-17**). Interestingly, only in the Fort Nelson and Cassiar TSAs is there an increase in the deciduous species proportion at the expense of coniferous species. In the other TSAs, there are increases in the proportions of some or all of the coniferous species at the expense of the deciduous species.

Translating Biophysical Changes into Socio-Economic Impacts

Translating the biophysical changes on the forests into socio-economic impacts is at best a series of educated guesses. It is possible, though, to speculate on where and how

Table 3. Employment, Income, and Revenue Coefficients per 1000 m^3 of harvest (from British Columbia TSA Socio-Economic Analyses)

Cassiar

	Employment (person-years)		After Tax Income		Government Revenue
	Direct	Indirect/Induced	Direct	Indirect/Induced	
TSA	0.10	0.03	$2,989	$919	
Province	0.77	1.15	$21,839	$24,138	$27,356
Federal					$10,919

Fort Nelson

	Employment (person-years)		After Tax Income*		Government Revenue
	Direct	Indirect/Induced	Direct	Indirect/Induced	
TSA	0.62	.36(.63)**	$21,076	$8,072($14,350)**	-
Province	0.69	0.98	$30,493*	$27,803*	$19,731
Federal					-

*Provincial estimates are for pre-tax income.
**Values in parentheses include in and outmigration associated with harvest level changes.

Fort St. John

Coniferous

	Employment (person-years)		After Tax Income		Government Revenue
	Direct	Indirect/Induced	Direct	Indirect/Induced	
TSA	0.48	0.28	$16,556	$5,889	-
Province	0.66	0.99	$22,000	$20,667	$24,433
Federal					$10,388

Deciduous

	Employment (person-years)		After Tax Income		Government Revenue
	Direct	Indirect/Induced	Direct	Indirect/Induced	
TSA	0.35	0.24	$10,000	$5,000	-
Province	0.39	0.58	$11,223	$12,086	$10,777
Federal			-	-	$6,791

Mackenzie

	Employment (person-years)		After Tax Income		Government Revenue
	Direct	Indirect/Induced	Direct	Indirect/Induced	
TSA	0.58	0.23	$19,885	$4,761	-
Province	0.89	1.32	$30,586	$24,523	$28,050
Federal				-	$14,039

Prince George

	Employment (person-years)		After Tax Income		Government Revenue
	Direct	Indirect/Induced	Direct	Indirect/Induced	
TSA	0.64	0.58	$22,420	$13,620	-
Province	0.66	0.98	$23,250	$23,280	$41,935
Federal			-	-	$11,065

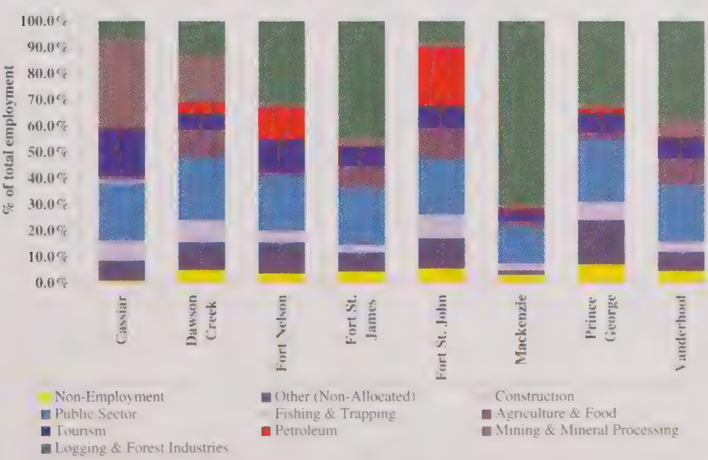

Figure 6. British Columbia Forest District employment dependencies.

some of the key impacts may come about. This section will address some of these topics.

Fire & Pest Suppression

Disturbance by fire and insect pests is a natural and significant regulator of the forest ecosystems in the Mackenzie River Basin (see **Figure 18** and the studies by Hartley, Kadonaga, and Sieben). Expenditures to suppress or manage these disturbances form a large share of total forest management outlays in this region. The average shares of total forest expenditures attributable to protection from pests and fire from 1988-93 were 95%, 63%, 36%, and 9% for Yukon and the NWT, Saskatchewan, Alberta, and British Columbia, respectively (Statistics Canada 1994).

The expenditures for fire suppression and control are large in absolute numbers and have been increasing in recent years (see **Figure 18**). From an average of $115 million dollars per year from 1971-1989, this has risen to nearly $180 million for the period 1990-1994 (in constant $1994). Part of this is due to the increasing incidence and extent of fires, but it also reflects the importance of the industry. Note that British Columbia, which generally has the smallest amount of area burned also has the highest expenditure on control.

If forests react as projected by the biophysical models presented here, either control expenditures will have to be significantly increased or much larger areas will be subject to more frequent burn episodes. This will impact upon the forest sector, and also all other users of the forests. It may also lead to, or hasten, transition of certain areas to other, more fire tolerant ecosystem types, such as grasslands.

Determination of Annual Allowable Cut

As the vast majority of forested land in British Columbia and Alberta is Crown land (see **Figure 5**), the annual allowable cuts (AACs) set by the BC Ministry of Forests (MOF) and by Alberta Environmental

Figure 7. Changes in potential growth wth changing climate, Mackenzie basin. Source: Adapted from Hartley and Marshall (this volume)

Protection determine to a large degree the annual harvest in each province. The MOF in BC is currently reviewing the AACs for all 36 Timber Supply Areas (TSAs) and 34 Tree Farm Licenses (TFLs) in the province. Under the Forest Act, the AAC determinations must be reassessed every 5 years. The procedure in Alberta is similar, with provincial determination of the Annual Allowable Cut for each Forest Management Unit (FMU) (Henderson 1994). In both provinces, the determination of AAC is a management decision that is influenced by, but is not strictly based upon, the type of calculations discussed below.

In BC, the first step of the Timber Supply Review process for reassessing the AAC involves conducting Timber Supply Analyses, which examine the physical and technical aspects of forest production and management. As part of these analyses, timber supply is projected for a 200 year time horizon, based upon "inventory information, expected growth and management practices" (Prince George Forest Region Planning and Inventory Section 1992; British Columbia Ministry of Forests 1994b; British Columbia Ministry of Forests 1994a; British Columbia Ministry of Forests 1995a; British Columbia Ministry of Forests 1995b; British Columbia Ministry of Forests 1995c). Sensitivity analyses are also performed in order to test the influence of a number of assumptions, including rates of harvest, timber harvesting land base, existing stand volume estimates, regenerated stand volume estimates, combined effects of land base and yield estimates, cutblock adjacency requirements, green-up period, minimum harvestable ages, and forest cover objectives for visual quality (Prince George Forest Region Planning and

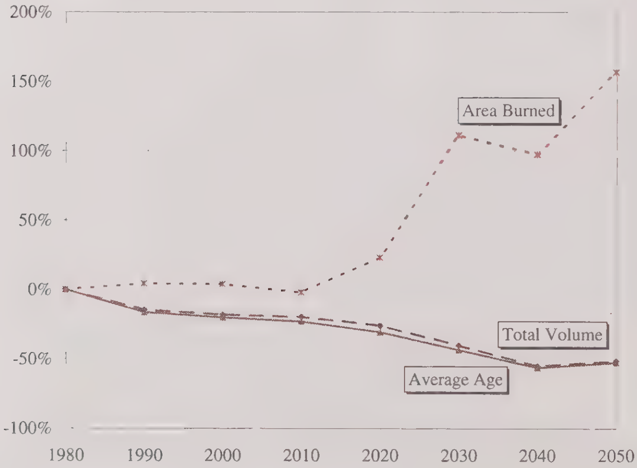

Figure 8. Aggregate changes with changing climate, Mackenzie Basin. Source: Adapted from Hartley and Marshall (this volume)

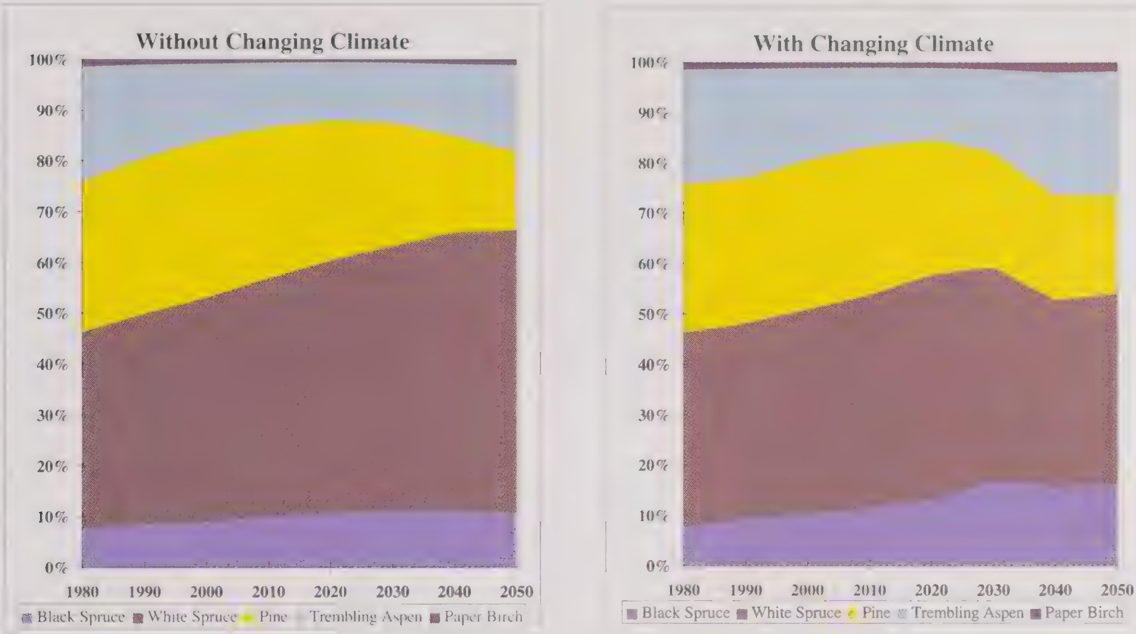

Figure 9. Volume proportion by species, Mackenzie Basin. Source: Adapted from Hartley and Marshall (this volume)

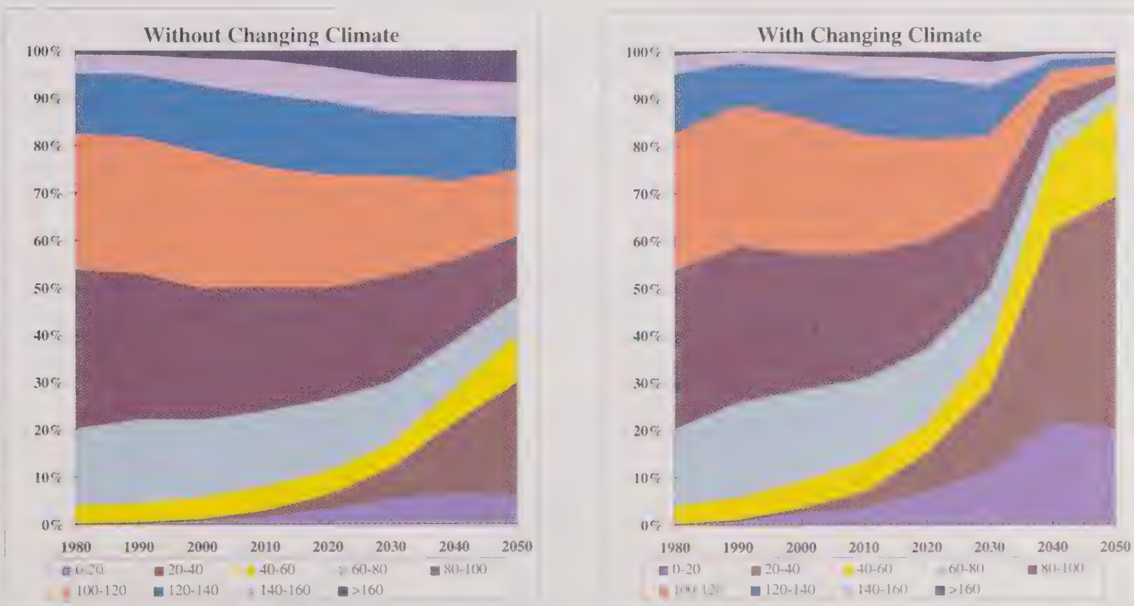

Figure 10. Volume proportion by age, Mackenzie Basin. Source: Adapted from Hartley and Marshall (this volume)

Figure 11. Changes in total volume, average age, and area burned with changing climate by British Columbia Timber Supply Area. Source: Adapted from Hartley and Marshall (this volume)

Inventory Section 1992; British Columbia Ministry of Forests 1994b; British Columbia Ministry of Forests 1994a; British Columbia Ministry of Forests 1995a; British Columbia Ministry of Forests 1995b; British Columbia Ministry of Forests 1995c). The current harvests, AACs, and long-term sustainable harvests postulated in these analyses are shown in **Figure 19** for the TSAs in the Mackenzie Basin. Cassiar and Fort St. John appear to be able to sustain larger harvests than present, whereas the other TSAs would see declines if sustained yield goals are to be met.

The results of these analyses are used by the Chief Forester in British Columbia for determining the AACs for TSAs and TFLs. Section 7, part (3) of the BC Forest Act (see Box) indicates specifically what factors the Chief Forester must consider in determination of the AAC, including physical, social, and economic considerations. In Alberta, AACs must be reviewed every 10 years. As in BC, future timber supply is estimated using simulation models and the sensitivity of the projections to various assumptions is examined (Henderson 1994).

A number of the factors to be considered in determination of the AAC in both provinces are potentially subject to influence by changing climate; the most obvious are volume estimates for existing stands, expected rate of growth, expected time of reestablishment, and losses due to insects, disease, and wildfire. Other factors, such as economic and physical operability, silvicultural treatments, biodiversity, and riparian habitats are also likely to be influenced by climate change in direct and indirect ways. It appears that in neither province has there been any consideration of the uncertainties posed by changing climate, even though the time horizons for timber supply estimates and for climate change are roughly similar.

Overall, it appears that changing climate may imply a decline in AACs in areas within the Mackenzie River Basin in both provinces. This is a result of declines in volume due to the inability of species to cope with the changing climate and the increased fire and pest risk. Increased management, particularly of disturbances, may alleviate the declines, but this will also significantly raise the costs of the industry.

Determination of Optimal Rotation

The biophysical impacts of changing climate on forests in the Mackenzie Basin will have significant implications for the management of forests in the context of optimal rotation. This is only one, and often a nar-

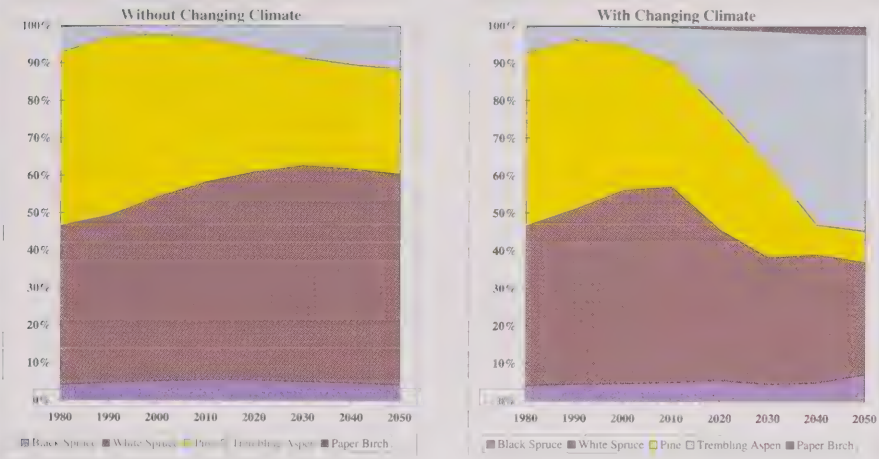

Figure 12. Volume proportion by species, Cassiar. Source: Adapted from Hartley and Marshall (this volume)

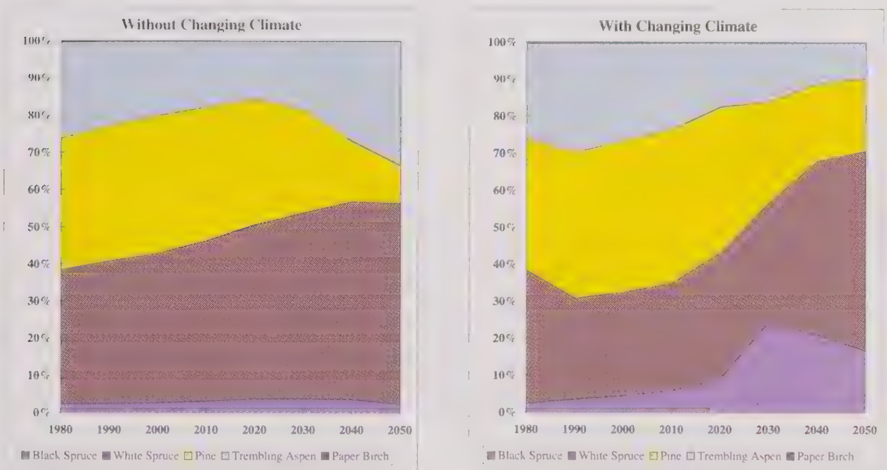

Figure 13. Volume proportion by species, Dawson Creek. Source: Adapted from Hartley and Marshall (this volume)

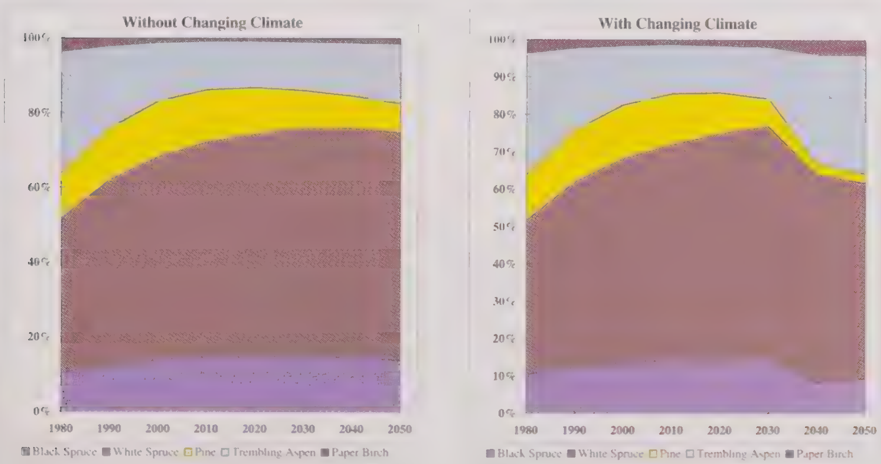

Figure 14. Volume proportion by species, Fort Nelson. Source: Adapted from Hartley and Marshall (this volume)

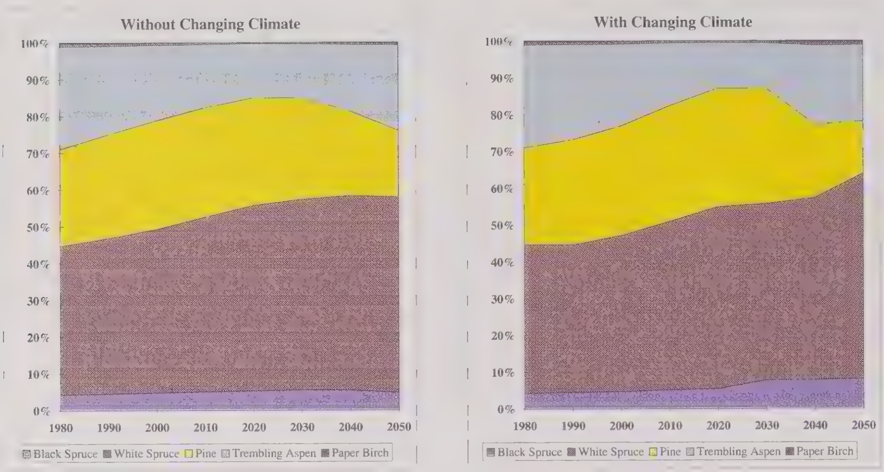

Figure 15. Volume proportion by species, Fort St. John. Source: Adapted from Hartley and Marshall (this volume)

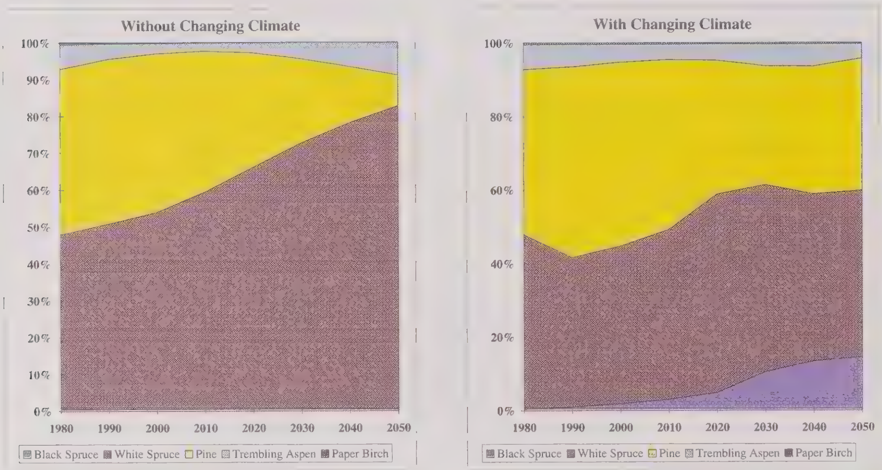

Figure 16. Volume proportion by species, Mackenzie. Source: Adapted from Hartley and Marshall (this volume)

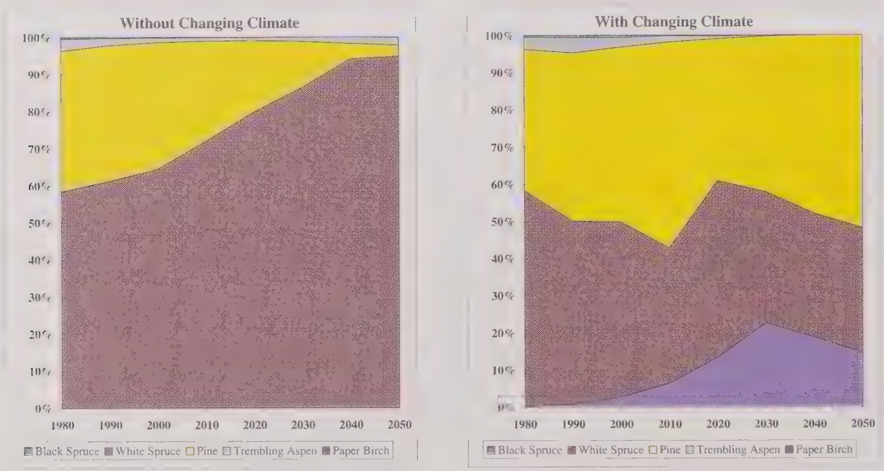

Figure 17. Volume proportion by species, Prince George. Source: Adapted from Hartley and Marshall (this volume)

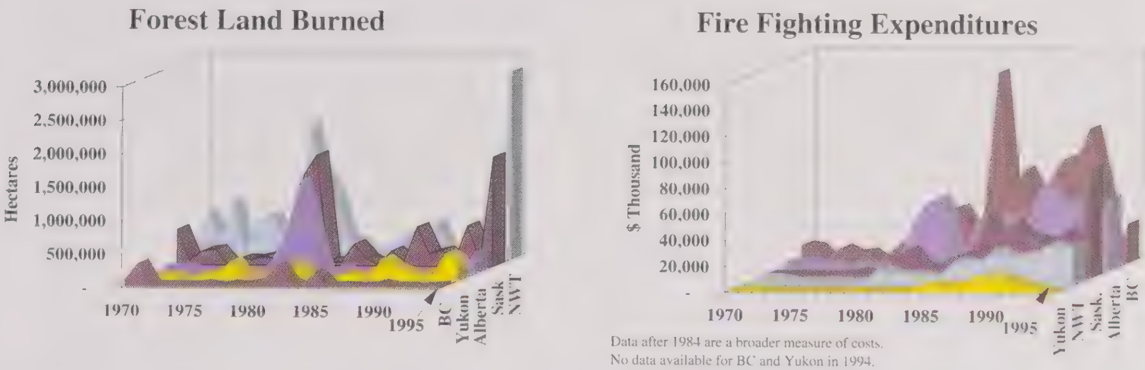

Figure 18. Forest Land Burned and Fire Suppression Expenditures by Province and Territory.

row, approach for considering the socio-economic impacts of biophysical changes in the forests, but it can lend some insight into forces influencing the various actors who have a role in managing forests.

Clark (Clark 1990) summarizes the traditional economic approach, developed by the German forester Faustmann, for determining optimal rotations of managed forests. The general conclusion of this framework is that forests should be harvested when the incremental benefit to be gained from allowing the trees to stand just balances the costs of doing so. This framework has traditionally only considered the timber value of the forests. However, several authors, notably Reed (Reed 1984) and Englin, *et al.* (Englin and Callaway 1993; Englin and Callaway 1995; Englin and Boxall 1996), have examined how the presence of fire risk, non-timber values, carbon sequestration potential, and other environmental amenities could influence the determination of optimal rotations.

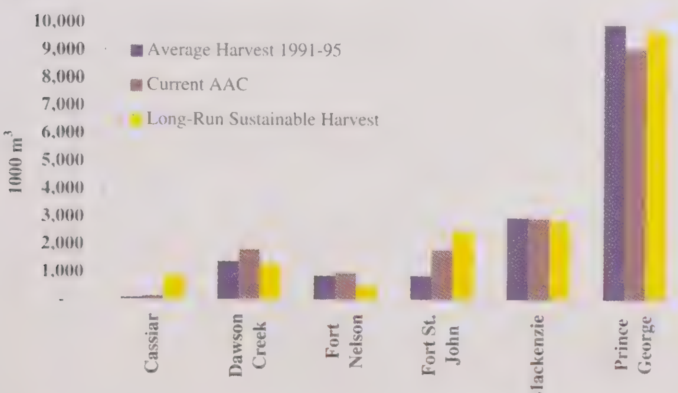

Figure 19. Current harvest, current AACs, and postulated long-term sustainable harvests for British Columbia TSAs.

Increases in the risk of loss from fires, pests, or diseases, assuming that these do not decrease significantly with age, inevitably lead to a shorter optimal harvest, as the likelihood of loss increases with time (Reed 1984). More rapid growth in younger trees and slower growth in older trees will tend to shorten rotations, unless existing rotations already involve harvesting younger age classes. Englin *et al.* (Englin and Callaway 1993; Englin and Callaway 1995) examine how the consideration of carbon sequestration potential will affect optimal rotations. Unlike earlier studies, which show that carbon sequestration inevitably leads to longer rotation periods because it represents a benefit of leaving the forest intact, they note that when the subsequent release of carbon from harvested timber is considered, this conclusion becomes ambiguous. For instance, if the harvested timber is burnt, there is no net increase in sequestered carbon, since the carbon stored in the timber is re-released into the atmosphere, thereby negating the benefit of leaving forests intact.

The consideration of non-timber values, recreational values, and other environmental amenities also has an ambiguous effect on the optimal rotation period, since these factors differ in how they are affected by changes in the volume and age of standing timber. These can range from shorter to longer rotations to situations when the optimal use of the forest will not include timber harvesting (Clark 1990; Englin, Boxall et al. 1995; Englin and Callaway 1995).

The main impression left by these analyses is that forest management involves a host of considerations, many of which are dynamic and interrelated. Because the recognized

BC Forest Act, section 7, part (3)

In determining an allowable cut under this section the chief forester, despite anything to the contrary in an agreement listed in section 10, shall consider

(a) the rate of timber production that may be sustained on the area, taking into account
- (i) the composition of the forest and its expected rate of growth on the area;
  - A. land base contributing to timber harvest
    - (a) general comments
    - (b) roads, trails, and landings
    - (c) economic and physical operability
    - (d) conventional/non-conventional harvesting methods
  - B. existing forest inventory
    - (a) forest inventory classification
    - (b) volume estimates for existing stands (VDYP estimates)
  - C. expected rate of growth
    - (a) site productivity estimates (site indexes)
    - (b) operation adjustment factors (these adjust TIPSY estimates)
    - (c) minimal harvestable ages (for existing and regenerated stands)
- (ii) the expected time that it will take the forest to become re-established on the area following denudation;
  - A. regeneration delay
  - B. not-satisfactorily restocked areas
- (iii) silvicultural treatments to be applied to the area;
  - A. silviculture systems
  - B. incremental silviculture
- (iv) the standard of timber utilization and the allowance for decay, waste, and breakage expected to be applied with respect to timber harvesting on the area;
  - A. utilization and compliance
  - B. decay, waste, and breakage
- (v) the constraints on the amount of timber produced from the area that reasonably can be expected by use of the area for purposes other than timber production; and
  - A. Integrated Resource Management objectives
    - (a) environmentally sensitive areas
    - (b) forest cover requirements
    - (c) green-up requirements (time to reach certain height)
    - (d) visually sensitive areas
    - (e) recreation and wilderness access
    - (f) biodiversity
    - (g) riparian habitat
    - (h) protected and designated study areas
- (vi) any other information that, in his opinion, relates to the capability of the area to produce timber
  - A. planning process
  - B. partitioned harvest (block AAC geographically within TSA)

(b) the short and long term implications to the Province of alternative rates of timber harvesting from the area;
  - A. alternative harvest flows

(c) the nature, production capabilities and timber requirements of established and proposed timber processing facilities;
  - A. timber processing facilities

(d) the economic and social objectives of the Crown, as expressed by the minister, for the area, for the general region and for the Province; and
  - A. local objectives
    - (a) minister's letter

(e) abnormal infestations in and devastations of, and major salvage programs planned for, timber on the area
  - A. unsalvaged losses
  - B. insects and disease (beyond what accounted for in yield and growth estimates)
  - C. wildfire

values provided by forests have increasingly come to include non-timber amenities, reliance on traditional rules for optimal rotation, which does not include non-timber values, will likely result in sub-optimal use of harvests. It may lead in some cases to shorter than optimal rotations from both a social and purely economic perspective. However, as discussed above, this may not always be the case, but it does appear to be so based upon the major effects of changing climate.

Concurrent Developments

Climate change is not occurring in a vacuum. The forest sector is facing a number of other trends and institutional changes with much more immediate effects. The Timber Supply Reviews mentioned earlier are just one of a large number of forest policy initiatives occurring in the British Columbia, including, among other aspects a new Forest Practices Code and Protected Areas Strategy, which has a goal a doubling of the amount of protected areas within the province (Forest Renewal BC 1995; Price Waterhouse 1995a). The forest products industry in Alberta has developed a code of practice which may be used as part of a certification process (Alberta Forest Products Association). A proposal has been submitted to create a combination of "Protected Areas" and "Special Management Areas" covering 8.5 million hectares in the Northern Rockies area of northeastern British Columbia (City of Fort St. John and North Peace Economic Development Commission 1995; Price Waterhouse 1995b). Numerous land treaties are being negotiated with First Nations. Canada has been embroiled in a number of softwood lumber disputes with the United States in recent years. Local producers are facing increased competition from plantations in tropical climates due to increased production in those regions and the opening up of trade with the passage of the North American Free Trade Agreement (NAFTA) and the General Agreement on Tariffs and Trade (GATT) (Marchak 1995).

It is in the context of these and other forces that the biophysical impacts of climate change on forests will play out. A Network of Centres of Excellence on sustainable forest management has recently been established, which will examine many of these issues (Sustainable Forest Management Network of Centres of Excellence 1996). For the moment, some indication of the effects of these trends and initiatives can be seen in the costs of harvesting and the structure of production.

Stumpage Rates

Stumpage fees in British Columbia, the price charged by the province to harvest timber, have risen steeply in recent years (see **Figure 20**). This is the case throughout much of Canada. These increases reflect in part a correction to historically low fees, which have been targeted as unfair subsidies by Canada's trading partners, especially the United States. The impact has already been significant, to the point that two major companies have sued the provincial government, claiming breach of contract on licenses obtained before the recent increases (British Columbia Report 1996a).

Technology Trends and Labour Force Utilization

Figure 21 shows historic levels of employment per unit of harvest for British Columbia in three sectors of the forest industry: logging, primary wood production, and paper and allied industries (pulp and paper production). A clear downward trend in seen over this period. Total employment, in fact, is only marginally higher in 1992 than it was in 1965 (75,238 versus 73,421 persons), even though harvest levels increased by 70% between these two years (74.0 versus 43.4 million cubic meters).

This reflects several possible trends within the industry, including technological change, realization of scale economies (i.e. greater efficiency of larger plants), and substitution for labour by other inputs for cost reasons. A consistent conclusion reached in a number of studies is that labour can, and has been substituted for by other in-

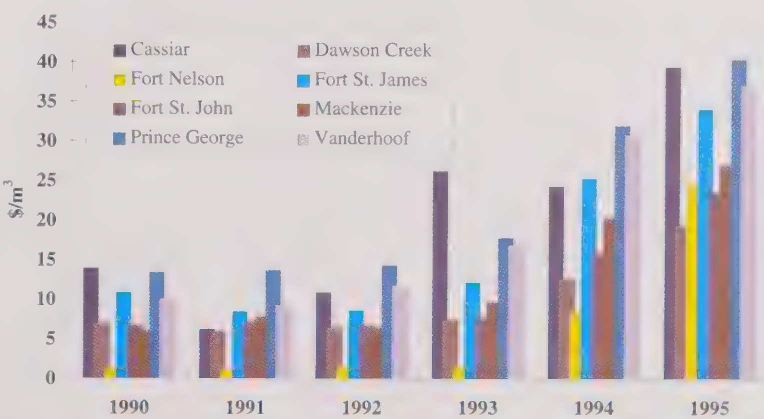

Figure 20. Average stumpage rates by British Columbia Forest District.

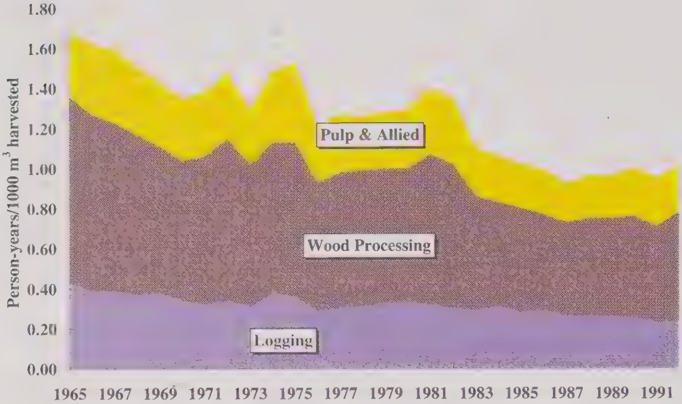

Figure 21. Employment per 1000 cubic metres harvested, British Columbia

puts, particularly energy and to a lesser extent capital, in the Canadian forest industry (Banskota, Phillips et al. 1985; Nautiyal and Singh 1985; Nautiyal and Singh 1986; Singh and Nautiyal 1986; Meil, Singh et al. 1988; Puttock and Prescott 1992). Puttock and Prescott (Puttock and Prescott 1992) point to increased automation as a response to increases in wage rates as one indication of the effect of changing input prices. The studies are less clear on the results for technical change and economies of scale, but Meil, et.al. (Meil, Singh et al. 1988) note that technical change has generally resulted in shifts away from the use of labour in favour of other inputs.

The tradeoff between increased productivity and reduced employment per unit output must be considered in any long-term analysis of the socio-economic impacts of climate change for this or other sectors. Whatever the cause of declining labour intensity in the industry, simply applying current ratios of employment per unit harvest to future levels of harvest is quite misleading. Unfortunately, this is the approach that has been used in the socio-economic analyses undertaken as part of the Timber Supply Reviews in British Columbia and other recent studies (Horne, Paul et al. 1991; Horne and Penner 1991; ARA Consulting Group Inc. 1993; Robinson Consulting & Associates Ltd. and Blackner 1994; ARA Consulting Group Inc. 1995; Bull and Williams 1995; Price Waterhouse 1995a; Bull and Williams 1996).

Impacts On Forest-Dependent Communities

Several recent studies have estimated the economic dependency on particular sectors of the economy of communities and regions within Canada, including parts of the Mackenzie River Basin. (Bone and Long 1995; Horne and Powell 1995b; Horne and Powell 1995a; Williamson and Annaraj 1995). Their methodologies and geographic coverage differ slightly, leading to some differences in their results.

In their study of settlement patterns for the Mackenzie Basin Impact Study, Bone and Long (Bone and Long 1995) classify as resource dependent those towns with populations under 30,000, with > 75% of the working population serving a single industry and its supporting services. Using this standard, they identify eight forest dependent resource towns within the Mackenzie Basin: Taylor, Hudson Hope, Chetwynd, and Mackenzie in British Columbia, and Whitecourt, Barrhead, Edson, and Hinton in Alberta. These are listed along with their current populations in **Table 1**. Williamson and Annaraj (Williamson and Annaraj 1995) use a slightly different standard (> 50% of employment income in basic sectors from forest related activities). They identify seven forest dependent communities in or near the Mackenzie Basin: Whitecourt, Hinton, and Mayerthorpe in Alberta and Mackenzie, Fort St. John, Vanderhoof, and Prince George in British Columbia. These are listed along with their current populations in **Table 2**.

Horne and Powell (Horne and Powell 1995a; Horne and Powell 1995b) have estimated the dependency on the forest sector of eight forest districts comprising the six timber supply areas in British Columbia which have at least some of their area within the Mackenzie River Basin. **Table 3** shows their results. The forest sector represents a significant share of the base economies of all of the districts, ranging from a low of seven percent in Cassiar to over seventy percent in Mackenzie.

Like other resource dependent and export-oriented communities, forest dependent communities have always been subject to forces outside of their direct control. They are fundamentally dependent upon the natural resource and also subject to the vagaries of global economic forces. Bone and Long (Bone and Long 1995) point out that, unlike mining or oil and gas dependent communities, forest dependent communities rely on a renewable resource. With proper management of the resource, there is potential for sustained, long-term development of the community.

Recent studies have questioned, however, the stability of forest-dependent communities and the potential repercussions of changes in the industry (Horne, Paul et al.

1991; Binkley, Percy et al. 1994; Beckley 1995; Bone and Long 1995; Price Waterhouse 1995a; Price Waterhouse 1995b; Robson 1995; Beckley 1996). Robson (Robson 1995) cites exhaustion of the resource base, market decline, competition from other producers, low profitability, technological change, and public policy shifts as driving forces of change in the forest industry in recent years. Similarly, Beckley (Beckley 1996) points to technological change, globalization of economy and culture, and attitude shifts (principally the emerging management paradigm of ecosystem health and diverse uses as opposed to sustainable yield of timber) as the key trends influencing forest dependent communities. Williamson and Annaraj (Williamson and Annaraj 1995) , expanding on the work of Apedaile (Apedaile 1992), discuss these and other forces, including the substitution of industrial goods for natural resources and global environmental advocacy.

Several studies have attempted to quantitatively estimate the local and regional economic impacts of potential changes in the forest sector (ARA Consulting Group Inc. 1993; Binkley, Percy et al. 1994, Bull and Williams 1995; Robinson Consulting & Associates Ltd. and Blackner 1994; ARA Consulting Group Inc. 1995; Price Waterhouse 1995b; Price Waterhouse 1995a; Bull and Williams 1996). These have primarily considered how changes in the annual allowable cuts may impact on key economic indicators, such as employment, earnings, and government revenues. The coefficients shown in **Table 3**, which have been used in the British Columbia Timber Supply Reviews, show that these impacts can be significant. Recall, however, that applying current ratios of economic impacts per unit harvest to future levels of harvest can be quite misleading, given other changes in the industry.

Changes in the physical structure of forests resulting from changing climate can have large effects on forestry-dependent communities via their impact on potential future uses of existing forested land. The actual effect that changing climate will have is unclear, but as discussed in earlier sections, it is potentially significant.

The time frames over which impacts from changing climate will occur are similar to those for many of these other factors. They are compatible with the capital structure of the industry, such that it can keep up with such shifts, but this may not be the case for forest-dependent communities. Robson (Robson 1995) describes how resource dependent and single industry communities have evolved from small, temporary sites to more permanent communities. The effect of changing climate may be to exert a regressive force on the historical trend to permanent communities, even as it reinforces the growth of fewer, larger forest centres. Reduced transportation costs due to technological improvements may, however, mitigate this effect.

Robson (Robson 1995) also states that due to "increasing costs, uncertain global economic tendencies, the slow decline of the post-war expansion period, on-going labour strife and a shift in the overall strategy of government, the forest dependent community has become less and less of a viable community alternative (Robson 1995)." Beckley (Beckley 1995; Beckley 1996) has questioned the concept of community stability interpreted as the persistence of communities as they currently exist. Community sustainability, using the notion of adaptability, the ability of individuals and institutions to respond to change, rather than persistence is a more accurate and useful notion.

Conclusions

Various forces are testing the resilience of the forest sector in general, and forest dependent communities in particular. Climate change poses another challenge. Unless there are greatly increased expenditures on forest management, including increased silviculture and fire and pest control, climate change in the Mackenzie Basin appears to imply significant reductions in potential future harvests and shorter rotations. In addition to reducing the absolute levels of potential harvests, continuing changes in climate will result in geographic shifts in particular species. Growing competition with agriculture and land for conservation or biodiversity protection may have further impacts. The actual effects that changing climate will have upon species mix, AAC determinations (and thereby harvest levels) and optimal rotations are unclear, but potentially significant. Whatever the impact, given the similar time horizons of the impacts of changing climate and many forest management policies, ignoring its effects may lead to a high price in the long-run.

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CO_2-Induced Climatic Change and Agricultural Potential in the Mackenzie Basin Case

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1. Introduction

The Mackenzie Basin, with a drainage area of about 1.8 million km^2, ranges from 52°N to 70°N, and includes portions of the Arctic, Boreal and Grasslands ecoclimatic regions (Statistics Canada, 1986). The main trunk of the Mackenzie River is the dominant feature, and the Liard, Athabasca and Peace River watersheds represent significant areas in the southern half of the Basin.

Much of the Basin is currently too cool and remote from markets to support a viable agricultural sector, but commercial agricultural production currently occurs in the southern reaches of the Basin, primarily in the Peace River region. Wheat and barley are the key cash crops, but canola has become increasingly important in the last 10 years. Forage production and pasture are the other main agricultural land uses. About 1.2 million ha of land in the Peace River region is currently used for commercial agricultural production (Agriculture Canada 1986 and 1990).

Scenarios for long-term CO_2-induced global climatic change suggest that the Basin's climate could be characterized by a warmer thermal regime, and this in turn, has contributed to considerable speculation about the implications of the Basin's physical potential to support commercial agriculture.

This assessment of the possible effects of potential long-term global warming on agricultural opportunities in the Mackenzie Basin was developed around 3 phases, with each phase providing an independent assessment as well as direction and input into subsequent phases. Phase I was a Basin-wide assessment of the extent to which several scenarios for global climatic change might alter agroclimatic constraints and land suitability for commercial production of spring-seeded cereal grains. Regions identified as having a physical potential to support commercial agriculture under Phase I were targeted for more intensive investigations. Under Phase II, the effects of a CO_2-induced climatic change on spring wheat yields were estimated. Phase III evaluates the effects of a potential global warming on the prospects for regional agricultural production potential, focusing on selected options for agricultural adaptation to climatic change.

Section 2 of this paper outlines the regional climatic change scenarios employed in this assessment, and then Sections 3, 4 and 5 summarize research conducted under Phases I, II and III respectively.

2. Regional Baseline Climate and Climatic Change Scenarios

The assessments of the possible effects of potential long-term global warming on agricultural opportunities in the Mackenzie Basin summarized in this paper are conducted relative to a baseline climate derived from weather observations from 1951 to 1980, and two scenarios for global climatic change. The climatic change scenarios were derived from the application of the Canadian Climate Centre (CCC) and Geophysical Fluid Dynamics Laboratory (GFDL) GCMs to 2 x CO_2 atmosphere experiments (Smith and Cohen, 1993).

Under the regional climatic change scenario derived from the CCC GCM, the greatest deviations from baseline temperatures were estimated for the winter months and estimates of temperature increases tended to be largest in the northern regions of the Basin.

The regional climatic change scenario derived from GFDL GCM was considerably different from the CCC scenario. The GFDL scenario estimates of summer temperatures for the southern half the Mackenzie Basin were in the 4°C to 6°C range above the baseline whereas the CCC scenario estimates ranged from +1°C to +3°C. The 2 scenarios estimated similar summer temperature increases for the northern half of the Mackenzie Basin.

The estimated changes in winter temperature also vary. The CCC-derived winter temperature increases tended to be in excess of 4°C above the baseline for most of the Basin. The GFDL scenario estimated increases were considerably less, and generally did not exceed 3°C.

Changes in precipitation patterns were also considerably different between the 2 scenarios. The CCC scenario estimates for the winter and summer months were in the ±25% over most of the Basin. The GFDL scenario estimated more severe deviations from the baseline, especially

during the summer months where estimated precipitation changes ranged from decreases of up 25% to increases in excess of 100%.

3. Phase I: An Agricultural Resource Potential Perspective

3.1 The Land Suitability Rating System for Spring-Seeded Small Grains (LSRS)

The LSRS (Agronomic Interpretations Working Group, 1992) was employed to estimate suitability of mineral soils throughout the Basin for commercial agriculture. The LSRS utilizes routinely collected soils, climate and landscape data and therefore it can be applied to broad regions such as the Mackenzie Basin. Furthermore, climatic properties are considered explicitly by the rating scheme and therefore it was well-suited to addressing climatic change issues.

The LSRS is based on rating the extent to which soil, climate and landscape represent limitations for the production of common spring-seeded grains (e.g. wheat, oats, barley). Each component is rated separately and assigned an initial value of 100. Then the extent to which a range of factors (e.g. effective growing degree days, drainage class, topography) impair crop production is determined and points are deducted to reflect the severity of the limitation. The overall land suitability rating ranges from 0 to 100, and is based on the most limiting of the three components.

3.2 Estimated Effects on Agroclimatic Properties

The baseline average frost-free period (FFP) estimated for the Basin was 132 days, which represents a substantial constraint to the commercial production of crops. Each of the climatic change scenarios implies a considerable extension of the FFP, with the greatest increase of 29 days occurring under the GFDL scenario.

With the longer FFP and higher temperatures associated with the climatic change scenarios, it was estimated that there would be substantial increases in effective growing degree days (GDD) over the FFP. Under baseline conditions, the Basin-wide average falls short of 1000 GDD, and represents a moderate to severe constraint to the production of spring-seeded cereals. Spring-seeded cereal typically require about 1600 GDD, and this threshold was reached on average under both of climatic change scenarios considered in this study.

The estimated moisture supply for the FFP, defined as the difference between precipitation and potential evaporation, was also sensitive to the climatic change scenarios. Substantial precipitation increases estimated under the GFDL scenario were offset by anticipated potential evaporation increases, resulting in only minor adjustments to the estimated seasonal moisture supply. However, the CCC scenario assumes only a modest precipitation increase, and this was more than offset by the estimated potential evaporation increase. As a result, the estimated seasonal moisture supply decreased under the CCC climatic change scenario.

3.3 Estimated Impacts on Agricultural Land Suitability

Under baseline conditions, it was estimated that nearly 6 million ha of mineral soils throughout the Mackenzie Basin are physically suitable for the production of spring-seeded small cereals. Moderately suitability agricultural lands accounted for nearly 36 million ha, while another 62 million ha of mineral soils were estimated to be unsuitable for spring-seeded cereals (**Table 1**).

The largest adjustments in land suitability for agriculture stemming from global climatic change were estimated under the GFDL scenario. A 41% increase in the total area of highly or moderately suitable land for cereals was estimated under this scenario, and this includes an estimated 64% increase in highly suitable land.

Under the CCC scenario, the total area of lands highly and moderately suitable for spring-seeded cereals is estimated to increase by 31%. This aggregation of highly and moderately suitable lands however masks an estimated 29% decline in land which is highly suitable for agriculture. Under the CCC scenario, the estimated temperature increases relaxed constraints associated with the current short,

Table 1: Estimated Impacts of Climatic Change on Agricultural Land Suitability in the Mackenzie Basin.

Suitability For Spring Seeded Cereals	Total Area in Mackenzie Basin	CLIMATE SCENARIO		
		BASE	CCC	GFDL
HIGH SUITABILITY	Ha ($x10^6$)	6.0	4.3	9.8
	Per cent	6	4	10
MODERATE SUITABILITY	Ha ($x10^6$)	35.4	50.3	48.7
	Per cent	34	49	47
NOT SUITABLE	Ha ($x10^6$)	62.0	48.4	[illegible]
	Per cent	60	47	43

NOTE: The assessments of the area suitable for spring-seeded cereals presented in Table 1 considered the 103 million ha of mineral soils in the Mackenzie Basin, and represent a biophysical potential. Consideration of other agricultural land uses, the use of non-mineral soils by agriculture and socio-economic factors which influence agricultural land use (e.g. current land use, distance to markets, competition for land between agricultural and non-agricultural activities, etc.) was beyond the scope of these land suitability assessments.

cool frost-free season, but in some regions of the Basin this potential benefit was offset by estimated increases in moisture deficits. As a result there was an estimated decrease in the land area with the highest potential for crop production under the CCC scenario.

3.3 Summary of the Agricultural Land Perspectives

With a considerable portion of the long-term global warming estimated for the winter months, the extent to which current thermal constraints on agriculture might be relaxed was not as pronounced as might be expected. In some locations in the Basin, including areas suitable for agriculture under baseline conditions, climatic change may result in less favourable moisture conditions. Overall, both climatic change scenarios implied an expansion in the area which has the physical potential to support commercial agriculture, with the largest increases estimated under the GFDL scenario.

4. Phase II: A Crop Yield Perspective

4.1 CERES-WHEAT Crop Model Overview

The version of CERES-WHEAT crop model used in this research is described in Ritchie and Otter (1985) and Godwin et al (1989). It predicts crop growth and yields for individual wheat varieties, and the model employs simplified functions which advance on a daily time step to estimate crop growth and yield as a function of plant genetics, daily weather, soil conditions, and management factors. Under Phase II, current agricultural practices were assumed. The remainder of this section presents selected findings for two sites. Beaverlodge at 55°N is in the Peace River region and within the area of the Basin which presently supports commercial agriculture. Fort Vermillion at 58°N is near the current climatic frontier for commercial agriculture.

4.2 Estimated Impacts on Crop Development

For the baseline period, the average number of days for spring wheat to mature was estimated at 118 days for Fort Vermillion and 124 days for Beaverlodge. The flowering-to-maturity or grain filling period was estimated at 42 days and 46 days at Fort Vermillion and Beaverlodge respectively (**Table 2**).

Both climatic change scenarios, *ceteris paribus,* implied a considerable reductions in the time required for spring wheat to mature and in the grain filling period. This estimated trend was more pronounced at both sites under the CCC scenario, where days to mature was reduced by about 20% and the estimated grain filling period was shortening by about 25%. Under the GFDL scenario, the estimated number of days required for spring wheat to mature was reduced by approximately 15% at each site and the average reduction in the estimated grain filling period was about 18%.

4.3 Estimated Impacts on Spring Wheat Yields

The estimated impact of the equivalent of a 2 X CO_2 atmosphere in isolation (i.e. CO_2 increases without climatic change) was an increase in spring wheat yields of about 30% at both sites. However, it was also estimated that potential yield increases stemming from elevated CO_2 levels would tend to be offset by the climatic changes specified under the CCC and GFDL scenarios. The warmer temperatures were estimated to shorten the time available for grain filling and therefore the climatic change scenarios did not necessarily imply more favourable conditions for cereal crops.

At Fort Vermillion, it was estimated that the cumulative effects of CO_2 increases and climatic change would result in a decline in mean wheat yields. This estimated trend was more pronounced under the CCC scenario, where yield declines in the 20% range were estimated compared to an estimated 12% decline under the GFDL scenario.

For Beaverlodge, it was estimated under the GFDL scenario that the yield improvements stemming from elevated CO_2 levels would be diminished but not completely offset by a more rapid crop ripening. Estimated spring wheat yields under this scenario were about 12% above those estimated given baseline conditions. The CCC scenario

Table 2. Estimated Impacts of Elevated CO_2 and Climatic Change on Spring Wheat at Two Sites in the Mackenzie Basin.

a) Beaverlodge

Crop Property	CLIMATE SCENARIO			
	BASE	BASE & CO_2 ↑	CCC & CO_2 ↑	GFDL &CO_2 ↑
Seeding To Maturity (Days)	124	NA	99	108
Grain Filling (Days)	46	NA	33	37
Yield (T/Ha)	4.9	6.4	4.0	5.5

b) Fort Vermillion

Crop Property	CLIMATE SCENARIO			
	BASE	BASE & CO_2 ↑	CCC & CO_2 ↑	GFDL &CO_2 ↑
Seeding To Maturity (Days)	118	NA	98	102
Grain Filling (Days)	42	NA	32	35
Yield (T/Ha)	2.7	3.2	2.1	2.4

however implied increases in crop moisture stress as well as a diminished grain filling period, and together these changes were estimated to more than offset the beneficial impacts of elevated CO_2 levels. Under the CCC scenario, mean spring wheat yields were estimated to be about 80% of the baseline mean.

4.3 Summary of the Crop Yield Perspective

Overall it was estimated that by itself elevated CO_2 levels would increase spring wheat yields. However warmer temperatures during the frost-free season would reduce the time required for crops to mature and significantly decrease the time available for grain filling. Shorter grain filled periods, when coupled with less favourable crop moisture regimes, were estimated to counteract the potential benefits of additional CO_2 and thereby suppress yield increases. This estimated trend was more pronounced under the CCC scenario than the GFDL scenario.

5. An Agricultural Adaptation Perspective

5.1 Selected Adaptation Strategies

It is estimated that the climatic change scenarios considered in this analysis would occur over a relatively long period (i.e. several decades) and therefore it is reasonable to expect that agriculture might adapt to climatic (and other) changes which ultimately influence the agricultural sector. In this assessment, the following three possible adaptation strategies were considered:

a) the use of a longer season spring wheat cultivar,

b) replacement of spring wheat with winter wheat, and

c) use of crop irrigation to eliminate crop moisture deficits.

This assessment is limited to estimating the effects of the selected adaptation strategies on crop development and wheat yields (**Table 3**). Methods summarized in the previous section to estimate crop development and yields were employed in Phase III. Analyses of other aspects of adaptation opportunities, including appraisals of the economic and technical feasibility of the strategies, are beyond the scope of this assessment.

5.2 Longer Season Spring Wheat Cultivar

Butte was the longer season spring wheat cultivar considered in this assessment, and it is sown in the northern regions of the US Great Plains. Relative to the estimated grain filling period for current cultivars under climatic change conditions, Butte was estimated to lengthen the grain filling period at Fort Vermillion and Beaverlodge by about 2 days under the GFDL scenario, and to have no impact on the length of the grain filling period under the CCC scenario. Overall, the selected longer season wheat cultivar was estimated to perform in a similar fashion to current cultivars under the climatic change scenarios and therefore this adaptation strategy would be expected to have only minor effects on the capacity of agriculture in the Mackenzie Basin to adapt to climatic change.

5.3 Winter Wheat

A winter wheat cultivar which has been used successfully in the northern regions of the US Great Plains was

Table 3. Estimated Impacts of Agricultural Adaptation Measures and Climatic Change on Wheat Yields at Two Sites in the Mackenzie Basin.

a) Beaverlodge

Adaptation Measure	% Change From Baseline Yield	
	CCC Scenario	GFDL Scenario
Longer Season Cultivar	-16	+12
Longer Season Cultivar & Irrigation	+14	+26
Winter Wheat	+ 1	+26
Winter Wheat & Irrigation	+41	+51

b) Fort Vermillion

Adaptation Measure	% Change From Baseline Yield	
	CCC Scenario	GFDL Scenario
Longer Season Cultivar	-25	-10
Longer Season Cultivar & Irrigation	+60	+78
Winter Wheat	-68	-68
Winter Wheat & Irrigation	-64	-64

NOTE: The longer season spring seeded wheat cultivar considered in this analysis was Butte. The winter wheat cultivar was based upon cultivars currently used in the northern regions of the US Great Plains. Analyses considering irrigation assumed irrigation levels sufficient to eliminate crop moisture deficits. Analyses summarized in Table 3 were based on biophysical conditions, and did not consider the socio-economic feasibility of the selected adaptation measures.

considered in this analysis. At Beaverlodge, the selected winter wheat cultivar was estimated to respond favourably to the climatic change scenarios. Winter wheat yields under the GFDL scenario were estimated to be about 25% above spring wheat yields under baseline conditions. Under the CCC scenario, which is characterized by warmer and drier conditions, the potential yield benefits associated with winter wheat were suppressed somewhat, but nevertheless, yields were estimated to be similar to spring wheat yields under baseline conditions.

At Fort Vermillion, winter crop damage was estimated to be severe and frequent under both the CCC and GFDL scenarios. These conditions would lead to occasional crop failure and therefore it should not be surprising that estimated long-term average winter wheat yields at Fort Vermillion under climatic change conditions were estimated to be well below baseline spring wheat yields.

5.4 Irrigation

Crop moisture deficits sufficient to reduce wheat yields were estimated under all climatic scenarios and were greatest under the CCC scenario. Hence it should not be surprising that irrigation coupled with either longer season spring wheat cultivars or winter wheat would be expected to enhance crop yields.

At Beaverlodge, yields estimated under the CCC and GFDL for irrigated longer season spring wheat cultivars were similar to yields under baseline conditions. Winter wheat coupled with irrigation was estimated to significantly increase yields relative to baseline conditions. The combined effects of longer season spring wheat cultivars, irrigation and climatic change on estimated wheat yields were similar at Fort Vermillion and Beaverlodge.

5.5 Summary of an Agricultural Adaptation Perspective

It was estimated that longer season spring wheat cultivars would not result in considerable increases in either the time required for crop maturation or in the grain filling period, and therefore this adaptation strategy would not counteract negative consequences of climatic change on agricultural prospects in the Mackenzie Basin. Converting from spring wheat to winter wheat may be an effective means to counter act the negative impacts of climatic change on wheat yields in the southern portion of the Mackenzie Basin, but elsewhere the warmer temperatures associated with the two climatic change scenarios would not be sufficient to eliminate winter crop damage. Conversion to winter wheat may be an effective strategy to enhance yields under climatic conditions for selected regions within the Mackenzie Basin, but the preliminary assessments from this study suggest this adaptation strategy may not be effective on a broad scale basis. Given the conditions specified under the CCC and GFDL scenarios, the elimination of crop moisture deficits by irrigation was estimated to enhance agricultural prospects in the Mackenzie Basin to a greater extent than the other two adaptation strategies considered in this assessment.

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Potential Impacts of Climate Warming on Hydrocarbon Production in the Northern Mackenzie Basin

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Introduction

Oil and Gas reserves are among the most economically valuable natural resources located in the Mackenzie Basin. The exploitation of these resources has been retarded by three factors. The first is the *remoteness* of the resources from major consuming regions. By far the largest reserves are located in the Mackenzie Delta and offshore in the Beaufort Sea. Any exploitation of these reserves would require transportation either through a very long pipeline or by tanker shipping over highly circuitous Arctic routes. The second factor is the harsh *climatic conditions* in the potential producing regions. Since the richest reserves are located above the Arctic Circle, cold weather, permafrost, and sea ice are major impediments to exploration, development, production, and transportation. The third retarding factor is the *environmental and cultural sensitivity* of the regions where the oil or gas would be produced, as well as regions through which it would have to be transported. Environmental sensitivity arises from the vulnerability or Arctic flora and fauna and the instability of permafrost landscapes. Cultural vulnerability arises from the high level of dependence of indigenous people on the environment, and from the vulnerability of their cultures to outside influences.

The prospect of climate warming in the Mackenzie basin could lead to the suggestion that one of these retarding factors — climatic conditions — will become less onerous. Thus, the economics of oil and gas exploitation may actually improve. This hypothesis is examined in this chapter. In order to provide the necessary background for such an examination, we first provide a brief review of oil and gas reserves and the history and current economic feasibility of oil and gas production in the Northwest Territories (NWT.) We also present results from an analysis of the impacts of hypothetical oil and gas production scenarios on the NWT economy.

Oil and Gas Reserves in the NWT

The greatest potential for new Canadian oil and gas production in the twenty-first century lies in the "frontier reserves," which include all offshore reserves and those located onshore in the Northwest and Yukon Territories. Of these, the estimated size of the reserves located in the NWT are second only to those of the Grand Banks.

The NWT reserves are located in three main areas: the Central and Southern area, the Mackenzie Delta / Beaufort Sea area, and the Arctic Islands. The reserves in the Southern and Central area are concentrated in two subareas : the first around the borders with Alberta and British Columbia, and the second in the Mackenzie Valley around Norman Wells (see **Figure 1**). In the 1980s, a pipeline was built to transport oil from Norman Wells south to

Figure 1. Northwest Territories Central and Southern Oil and Gas Areas.

Zama Alberta. Norman Wells is now the most important oil production area in the Canadian North, and the only frontier oilfield in permanent production.

Located at the northernmost extent of the Mackenzie Basin, the Delta / Beaufort Sea region is estimated to contain the largest reserves of oil and gas in the NWT (See **Table 1**). Major proven gas reserves are onshore, including those at Taglu on Richard Island and Parsons at the base of the Tuk Peninsula, while most of the larger oil reservoirs are offshore (see **Figure 2**). Of these, the most important is Amauligak, located 70 KM offshore at a depth of about 30 M. With reserves estimated at 350 million barrels, it is about half the size of the Hibernia reservoir. (The Arctic Islands are located outside the Mackenzie Basin, and are therefore not part of our study area.)

Table 1. NWT Conventional Recoverable and Potential Oil and Gas Reserves.

Oil (barrels x 10^9)

Area	Conventional Recoverable	Potential
South and Central	0.30	0.50
Mackenzie Delta/ Beaufort Sea	1.17	2.50
Arctic Islands	0.40	0.50

Natural Gas (cubic ft. x 10^{12})

Area	Conventional Recoverable	Potential
South and Central	0.60	4.0
Mackenzie Delta/Beaufort Sea	10.50	24.0
Arctic Islands	18.0	15.0

Source: Dingwall (1990)

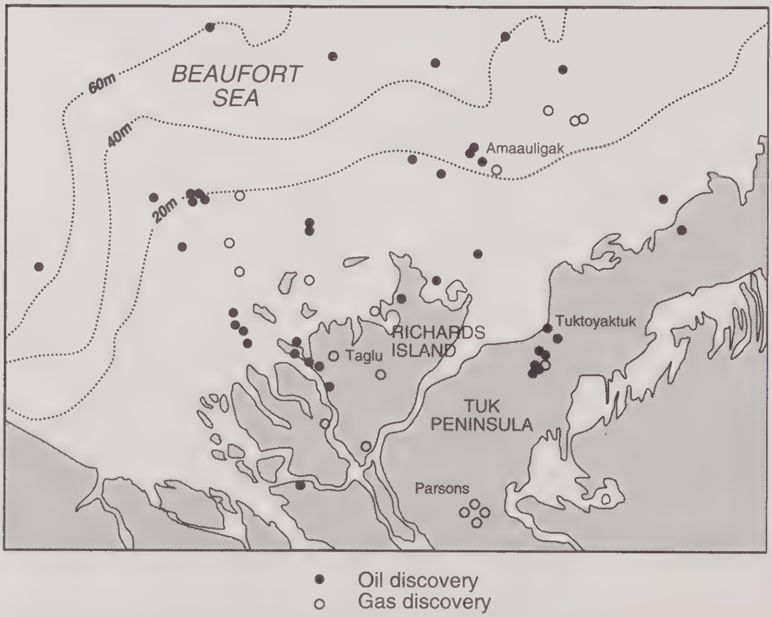

Figure 2. Beaufort Sea / Mackenzie Delta Significant Discoveries

Mackenzie Delta/Beaufort Sea Scenarios

During the 1970s there was a major proposal by a consortium of oil and pipeline companies to build a natural gas pipeline down the Mackenzie Valley to exploit gas fields in the Delta. While this proposal was rejected on the grounds that the pipeline might cause environmental damage and interfere with the traditional activities of indigenous people, exploration activities continued up until the late 1980s. They have since virtually ceased, due largely to the low prices of oil and gas. However a recent study (Croasdale and McDougall, 1992) has identified a number of oil production scenarios for the Delta/Beaufort region that could be economical in the not too distant future. (Gas production is not judged economically feasible in the near future.) Three major oil production scenarios may be described as follows:

Small pipeline / onshore: extension of the Norman Wells Pipeline to the Delta to produce oil at a rate of approximately 25,000 barrels per day (bpd).

Large pipeline / offshore: construction of large diameter pipeline from Alberta to Richards Island, with connection to an underwater pipeline to exploit Amauligak and other offshore reservoirs at a rate of 80,000 bpd.

Tanker / offshore: transportation of oil from Amauligak by tanker to Montreal (eliminating the need for any overland pipeline) at a rate of 35,000 bpd.

Table 2 provides current estimates of the "break-even" oil prices for the three scenarios. Oil companies would probably require a "risk premium," so much higher prices might be needed before large-scale projects were undertaken.

Table 2. Base Case Economics for Three Delta/Beaufort Scenarios.

Scenario	Barrels per Day	Oil Price Required for a 10% Return	Oil Price Required with Technology Uplift[3]
Price Figures are in 1992 U.S. Dollars			
Onshore - Small Pipeline	25,000	26.75	21.20
Offshore - Large Pipeline	80,000	22	18.80
Offshore - Marine Transport	35,000	21	17.80

Source: Croasdale and McDougall, 1992

Potential Impacts of Delta / Beaufort Scenarios

Any of these scenarios may be expected to have major economic, environmental, and cultural impacts in the North. In order to assess the economic impacts of the three scenarios, we constructed a dynamic multiregional input-output model. This model predicts output and income effects on the economies of NWT and other Canadian regions over the exploration and development phases of a hypothetical oil project. **Table 3** compares projections of the additional personal income that would accrue to residents of NWT and to all residents of Canada under the three scenarios. One interesting result is that a relatively small proportion of economic benefits of all scenarios are captured by the NWT economy. This is because most of the equipment and much of the development services would be provided by firms from central and western Canada. Another important result is that the magnitude of economic benefits varies across scenarios. The marine transport scenario has the smallest impacts because of its relatively low requirements for local labour and locally supplied inputs.

Potential environmental impacts may provide the greatest obstacle to large scale activity in the Delta/ Beaufort region. While environmental damage due to spills, fires, disruption of natural habitat, etc. may occur in any oil and gas development region, the potential for such damage in the Northern Mackenzie Basin is increased due to the vulnerability of the permafrost terrain. Also, given the highly sensitive marine ecosystems along transportation routes, large-scale tanker transportation of Delta/ Beaufort oil would involve considerable environmental risk.

Table 3. Impacts of Three Delta/Beaufort Scenarios on NWT Economy.

Scenario	Duration of Development Phase (years)	Added Personal Income (NWT)	Added Personal Income (Canada)
Income Figures are in millions of 1992 Canadian Dollars			
Onshore - Small Pipeline	8	290	927
Offshore - Large Pipeline	10	1086	3423
Offshore - Marine Transport	5	170	539

A major project could also have negative cultural impacts, especially on indigenous people. For example, despite the economic benefits of employment opportunities, taking advantage of those opportunities may involve relocation and diversion of energies away from traditional activities (Centre for Sustainable Regional Development and the Pedzeh Ki First Nation, 1995.) Also, any environmental impact that affects the numbers or distribution of migratory animal could have a devastating impact on the traditional economy.

Potential Impacts of Climate Change

The general circulation models employed in the MBIS predict increased air temperatures under the $2XCO_2$ scenarios ranging from 2.0°C in September to 9.2°C in March in the Mackenzie Delta area. Changes in air temperature, however, are unlikely to have any significant impact on the economics of oil production. Instead, the consequences of this warming, including changes to the sea ice, changes in the lengths of operating seasons, and changes to permafrost, are relevant to oil operations.

Sea Ice: The base maximum ice thickness at 70° North may decrease from its current 1.7M to between 1.4M and .7M; the southern extent of the polar pack ice may recede from the current 72-75°N to about 75-80°N; the open water season may increase from the current 60 days at 72°N to between 90 and 150 days; and, because of the increase in the area of open water, the two year wave height may increase from 1.6M to 1.9M (Agnew, 1993.) Higher wave height could accelerate coastal erosion, which is already a major problem in the Delta and Tuk Peninsula (Solomon, 1994.)

Permafrost: It is difficult to predict how much or how quickly climate warming would affect permafrost depth and distribution. Recent research suggests that in the Mackenzie Delta, warming would not significantly alter the distribution of permafrost, but may increase the depth of the active layer by about 20% (Dyke, 1994.)

Significant effects on permafrost may, however, occur further south in the Mackenzie Valley where a pipeline would be built. Slope instability may be expected to increase throughout the region as the result of receding permafrost (Aylsworth and Egginton, 1994.) Since changes in permafrost due to climate warming would occur quite gradually, affects are relatively long term.

Operating Seasons*:* Since temperatures in all seasons are projected to increase, the summer season can be expected to become longer and the winter shorter. This will have significant impacts on oil and gas activities. Its effect on overall costs is ambiguous however because some activities are more easily done in summer while others are more easily done in winter.

Our main conclusion is that climate change has both positive and negative impacts on the economics of most aspects of oil and gas development. We summarize these impacts in **Table 4**. One critical factor reflected in this table is the effect that climate warming will have on the length of summer and winter seasons. Longer summers will provide more ice free days, therefore expanding possibilities for marine transportation both in the Beaufort Sea and on the Mackenzie River. However, longer summers will actually *reduce* the work period for onshore development and exploration and for pipeline construction. This is because of the difficulties associated with travelling and working in a permafrost environment while the active layer is thawed. For example, overland transportation is generally cheaper and easier in the winter because of the existence of ice roads for trucks and the ability to use snowmobiles. In the summer, movement is difficult because vehicles can easily become bogged down or cause permanent damage to the permafrost, therefore more expensive air transportation is often needed. Also, environmental cleanups are more difficult in the summer because spilled contaminants move more quickly when there is water present at the surface. Thus, winter is the most active work season for many onshore activities.

The positive and negative impacts listed in **Table 4** are based on comparison of the current climate regime and a hypothetical future climate regime — that is, they treat the future as if it were known. When we take account of the uncertainty implied by the potential for climate change, the picture becomes far more negative.

For example, the short-term affect of the expectation of changes in the permafrost regime will almost certainly be an *increase* in the cost of building a pipeline in the next two or three decades. The economic lifetime of a pipeline is at least twenty-five years — a period over which significant climate change may occur. This means that it would have to be designed to be suitable in both the permafrost conditions that are observed at the beginning of its lifetime and those that are expected to exist at the end of its lifetime. Thus, at any point in time it must be "over-engineered." For this reason the *prospect* of climate change has probably *already* increased the cost of pipeline transportation for oil produced in the Delta / Beaufort region.

As for offshore production, reduced maximum ice depth could, in theory, reduce the cost of development and production platforms, which would have to resist lesser ice loads. Reducing the necessary tolerance for these types of capital equipment could lead to large reductions in total project costs. However, it is highly unlikely that any such reduction could occur in the foreseeable future because engineering standards for Arctic offshore operations are based on "100 year " ice loads and could not be changed on the basis of uncertain climate change projections (Croasdale, 1993; McGillivray *et. al.,* 1992.) Therefore any cost reductions would occur only in the very long term.

Table 4. Potential Impacts of Climate Change on Oil and Gas Activities

Activity	Positive Impact	Negative Impact
Onshore Exploration/Development	• less permafrost to drill through • more ice-free days for Mackenzie barge traffic	• shorter winter work season • increased difficulty containing spills due to more surface water
Offshore Exploration/Development	• longer exploratory and development drilling season • possible reduction to cost of permanent production rigs	• coastal erosion/ higher waves • more difficulty containing spills in shallow water
Pipeline Construction	• contraction of permafrost zone	• shorter winter work season • increased uncertainty about permafrost distribution • risks and damage due to landslides
Marine Transportation	• longer ice free season • possible reduction in cost of tankers	• coastal erosion may threaten onshore storage and other facilities • higher waves

Conclusions

Our assessment indicates that there is little reason to expect climate change to increase the potential for major oil and gas development in the Delta / Beaufort area. Consideration of

all activities required by such a development reveals many ways in which climate warming would actually increase, rather than decrease, the costs of exploration and development activities. This is especially true for onshore activities.

The prospect of climate change means that any major long-term project is faced with the dilemma that environmental conditions are likely to change during its lifetime. Environmental impact assessment of major projects, especially in the North, will have to address this issue in the near future. Since uncertainty over climate change implies that facilities such as pipelines must be designed to tolerate a broader range of possible conditions, it will almost certainly increase development costs, at least until climatic conditions stabilize.

The one aspect of oil and gas exploitation in the Delta / Beaufort region that might benefit from climate change is tanker transportation, which could become economically viable in an environment of reduced ice. Our analysis indicates that a tanker-based development would bring little economic benefit to the NWT. Such a development raises serious environmental concerns regarding not only the Beaufort/Delta region but also the entire shipping routes through the Northwest Passage to Montreal or around Point Barrows to Vancouver. Unless these concerns can be adequately addressed, such a scenario would not be very attractive to residents of the North. The key impediment to tanker transportation is the possibility of a catastrophic spill. In light of this, research assessing the risks of tanker transportation, both by the eastern and western routes, would be of great value at this time.

Notes

1. This chapter reports on only part of a study examining the potential impacts of climate change on various aspects of energy supply and demand in the Northern Mackenzie Basin. The full report (Anderson, Kliman, and DiFrancesco, 1996) is available on request from the McMaster Institute for Energy Studies, McMaster University, Hamilton, Ontario, L8S 4M4.

2. We focus on the NWT because it contains the largest new oil and gas reserves in the basin and because climate change impacts are likely to be greatest in the northern part of the basin. No attempt is made here to assess impacts of climate change on other hydrocarbon resources in the Mackenzie Basin, such as gas reserves in northeastern British Columbia or Tar Sands in northern Alberta.

3. "Technology uplift" refers to the application of new production technologies that will be available in the not too distant future.

4. Unlike the provincial governments, the NWT government does not receive royalty payments for oil and gas produced within its borders. Therefore, the economic benefits occur almost exclusively during the exploration and development phases of an oil or gas project. These are the only benefits assessed in the model.

5. More details on the economic impact analysis are provided in Anderson, Kliman, and DiFrancesco (1996.) A complete technical reference and disaggregate presentation of results are found in DiFrancesco (1995.)

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Climate Change and Tourism in the Mackenzie Basin

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Abstract

Prospects of global climate change may present challenging physical, biological and managerial problems for national parks and wildlife in the Mackenzie Basin. Studies were undertaken to assess the possible implications of climate change for water-based recreational activities in Nahanni National Park Reserve (NNPR) and for hunting of the Bathurst caribou herd. With regard to the former, under conditions of increased mean annual temperatures and increased precipitation, hydrological changes may have little effect on the execution of river recreation, whereas forest fire and ecological changes may have significant impacts on the experiences of visitors. With regard to the latter, analyses of climate change scenarios indicate a possible increase in winter snowfall, and increased insect harassment of caribou in the summer, due to an increase in average monthly temperatures. Computer simulation models representing conditions of increasing levels of insect harassment and greater snowfall suggest climate change may reduce the number and health of caribou in the Bathurst herd, resulting in reduced hunting opportunities. Management strategies to respond to the uncertainties associated with environmental change are presented for both recreational activities.

Introduction

Prospects of climate change may present problems for national parks and protected areas which are designated to preserve various natural ecosystems. Changes in climate may modify the biophysical characteristics of parks and wildlife resources in the North and affect their human uses. If the physical and biological elements which provide the backdrop for visitors are altered by a changing climate, the experiences available to tourists may also be affected. Changes in recreational opportunities could further stress natural ecosystems and resources in locations such as the Mackenzie Basin through altered visitor seasons, and possible changes in infrastructure requirements. These natural resources constitute the bases of much of the tourism in the North which is a significant component of the northern economy.

Tourism in the Northwest Territories

At a very basic level, tourism supply can be viewed as comprising three fundamental components: attractions, transportation, and infrastructure (Wall and Brotton 1993). All three components are impacted by climate. Attractions in the North are both natural (these are subjected to both consumptive and non-consumptive use) and cultural. The former include hunting, fishing, and river recreation resources, while the latter are rooted in the lifestyle of the native people, both past and present (Wall and Brotton 1993). Transportation networks in the North are connected between the travelers' origins and destinations, and within the destination area. The latter networks are crucial for tourism; however, those in the Northwest Territories (NWT) are not highly developed. Transportation in many areas is unreliable, and includes winter roads which are available for only a short time each year. Due to the high cost of development and construction in the North, transportation networks have not been established specifically for tourism; this is unlikely to change if the climate changes.

The tourism industry in the NWT is characterized by remoteness, associated high costs of travel to the territory and within it, and long, cold winters (Wall and Brotton 1993). These circumstances act as constraints on development, with a resultant small, specific market segment. Nevertheless, the social and economic value of tourism in the NWT is evident. For example, the travel industry accounts for 2 000 person-years of direct employment in NWT, and is the third largest employer amongst the territory's economic sectors. The value of travel expenditures per year in the NWT is approximately \$133.8 million, of which \$88.8 million is non-resident business and pleasure expenditures (Derek Murray Consulting Associates *et al.* 1994). In the summer of 1992, the number of non-resident person trips was 64 000, with total tourism expenditures of \$64 million. Twenty-eight percent of visitors stated that they fished, and ten percent engaged in outdoor adventure package touring (Derek Murray Consulting Associates *et al.* 1994). In fact, fishing and hunting products generate the largest single economic impact for the NWT's tourism industry (Derek Murray Consulting Associates *et al.* 1994). At the same time, much non-consumptive tourism is directed to parks and protected areas. In the 1992-93 tourism season, the government of the NWT spent \$2.4 million on tourism marketing, and received \$4.6 million in tax revenue. In addition, the total direct and indirect wage income attributed to tourism in the NWT was \$25.4 million (Derek Murray Consulting Associates *et al.* 1994).

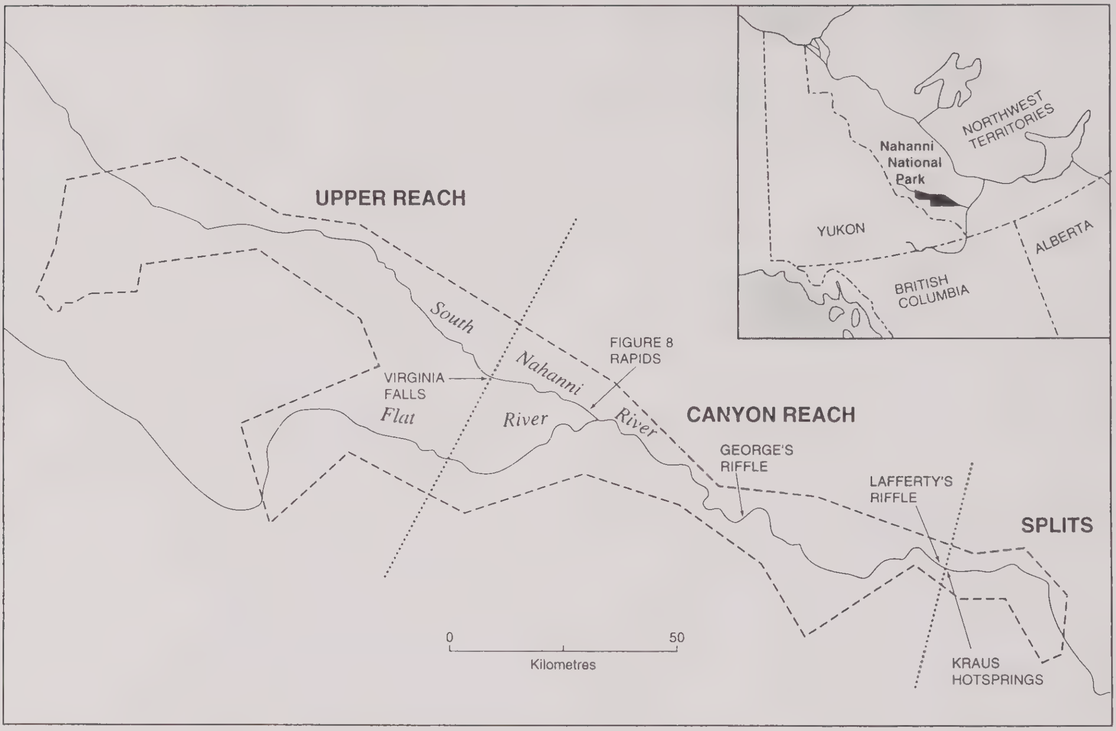

Figure 1. Location of Nahanni National Park Reserve (NNPR).

Thus, tourism is an important economic sector in the North which relies heavily on natural resources for both consumptive and non-consumptive uses and, consequently, is susceptible to the vicissitudes of climate.

Research Strategy

As projections indicate that the magnitude of climate change may increase with latitude, national parks and wildlife resources in northern Canada are of particular interest because of their potential to be vulnerable to variations in climatic parameters. Nahanni National Park Reserve (NNPR), located in NWT (**Figure 1**), was chosen as a case study for determining the biophysical and recreational impacts of potential climate change on a northern park. National parks in Canada have a dual mandate of preservation and use. This mandate is also relevant to the broader tourism industry if tourism is to be developed in a sustainable manner and the resources on which it depends are not to be destroyed. A brief description of the current climate, hydrology, ecology and visitor use of NNPR will be given, followed by an assessment of estimated changes to temperature and precipitation regimes as suggested by four climate scenarios, leading to an evaluation of likely implications of the latter.

Caribou is one species of wildlife used by both residents of and visitors to NWT. Prior to the influence of white society, Dene in the south and Inuit in the North lived almost exclusively by hunting and fishing, and for those who dwelled within the range of the caribou, it became the focus of many of their activities for sustenance, tools, and shelter (Arnold 1989). A majority of native people in the NWT still hunt caribou, and for many northern people, caribou are an important source of "country food" (Arnold 1989). Because hunting resources are renewable resources, they can be used year after year if properly managed. At the same time, caribou are an important quarry for visiting hunters and, as such, they are a significant tourist attraction.

Of the four subspecies of caribou in NWT, barren-ground caribou have the widest distribution, are the most abundant, and have the greatest economic importance (Barren-ground Caribou of the Northwest Territories 1992).

There are nine major herds of barren-ground caribou, of which three are found within the Mackenzie Basin portion of the NWT; these are the Bluenose, Bathurst, and Beverly herds. The Bathurst herd was chosen for study because it is accessible to more people in the NWT than any other herd. The herd is close to Yellowknife, home for nearly one-quarter of all people in the NWT, and for many years winter roads constructed across frozen lakes have provided hunters with access to the herd (Heard 1989). The east shore of the Mackenzie River south of Fort Norman is the most westerly point of the Bathurst herd's range which extends east as far as Perry River (**Figure 2**). There is likely some winter range overlap between the Bathurst and Bluenose herds (the latter herd's range is northwest of the Bathurst's), and between the Bathurst and Beverly herds (the latter herd's range is southeast of the Bathurst's) (**Figure 3**).

Thus, a case study approach was adopted which investigated NNPR (Staple 1994) and the Bathurst caribou herd (Brotton 1995) and each of these investigations will be discussed in turn.

NNPR Study

Objectives

The specific objectives for this study were to assess the possible implications of climate change for tourism and recreation in NNPR.

Methods

The study consists of six steps. The initial step was to determine the current annual climatic regime in NNPR in terms of monthly temperature and precipitation values. Second, current water-based recreation in the park was investigated in terms of the length of the season, peak season, and the number of visitors. The third step was to establish links between the present climate and recreation in the park. Links are those factors which are directly affected by climate and, in turn, influence either the execu-

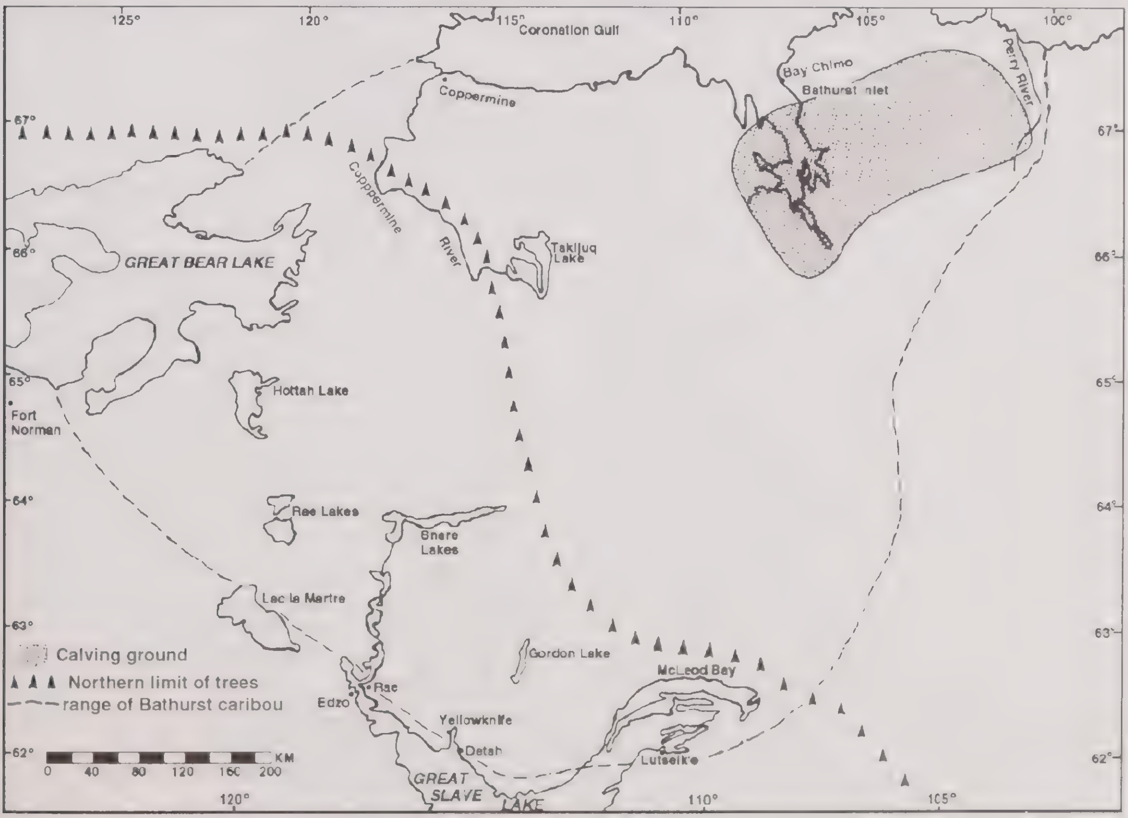

Figure 2. The Bathurst caribou range and calving ground.

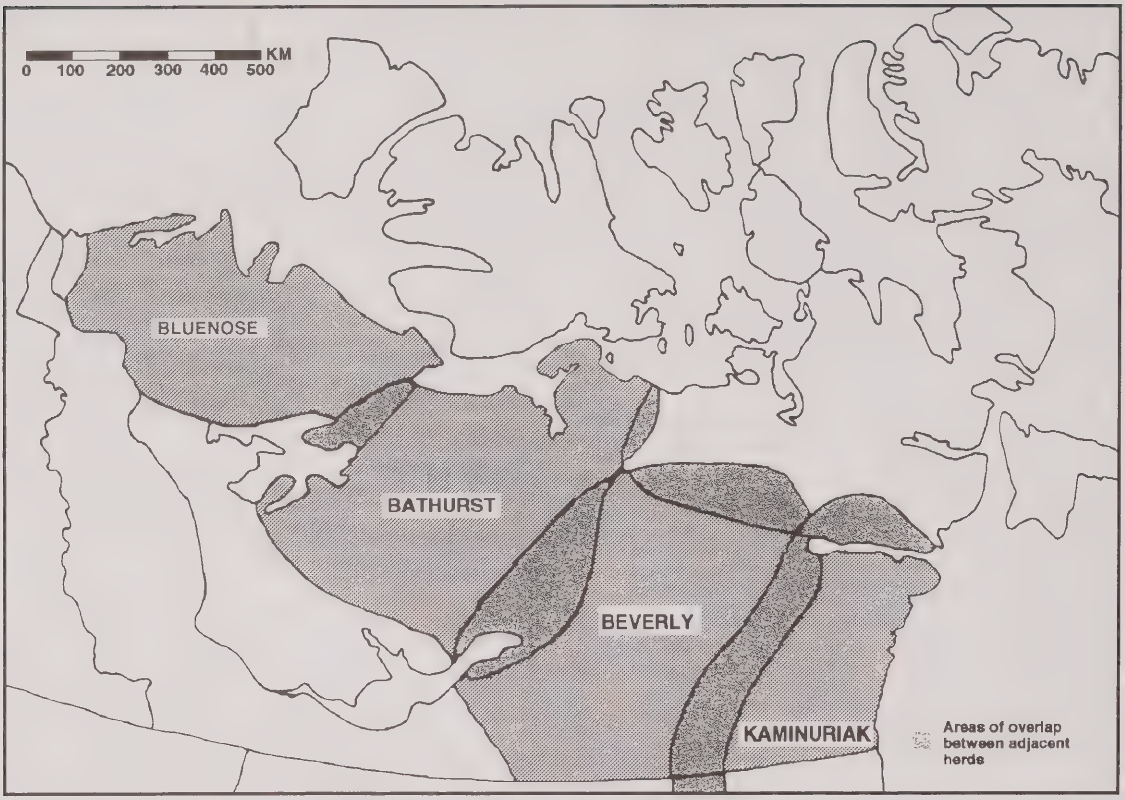

Figure 3. Approximate range of mainland barren-ground caribou herds in the Northwest Territories.

tion or enjoyment of the recreational activity. Hydrology, ecology, and the occurrence of forest fires are links in this study.

The fourth step was determining the park's future monthly temperature and precipitation characteristics through the use of four climate change scenarios provided by Mackenzie Basin Impact Study (MBIS) participants (these are described elsewhere). Assuming that the same links which currently affect climate and recreation will apply in the future, the fifth step was to ascertain the effects of future climate upon the hydrological and ecological conditions and the frequency of forest fires in the park. The sixth step was evaluating how changes in the linking factors would influence the execution and enjoyment of recreation.

MBIS participants contributed information used in this study, including current and future climatic (temperature and precipitation) characteristics, future runoff values and forest fire conditions of the South Nahanni region.

Site Description

Climate of the South Nahanni Watershed

The South Nahanni River watershed, including NNPR, currently has a continental climate, typified by short, warm summers and long, cold winters (Parks Canada 1983). Arctic and Pacific air masses, varied topography, and high latitude are factors controlling such climatological parameters as temperature and precipitation in the park.

The thermal regime of the South Nahanni basin varies temporally and spatially. The continentality of the region results in a 35.5 degree Celsius difference between summer and winter mean monthly temperatures. In addition, temperatures of the basin vary spatially due to topographical influences.

Precipitation patterns of the Nahanni region also vary temporally and spatially. Generally, most of the basin's 530 mm of precipitation falls in summer. Winter precipitation, at 150 mm, is light, due to the presence of dry, cold Arctic air.

Hydrology of the South Nahanni River

The subarctic nival hydrological regime of the South Nahanni River is closely associated with the climate conditions of its watershed. Peak flows generally occur during the last three weeks of June due to high altitude snowmelt in northern portions of the basin.

The South Nahanni River has gained an international reputation for quality as a wilderness river experience. The river within the park can be divided into three reaches: the first, Upper Reach (Rabbitkettle Lake near the western boundary to Virginia Falls), and the third, the Splits (Kraus Hotsprings to the eastern boundary), are classified as grade I (very easy) on the international scale of river difficulty. The second reach, Canyon Reach, is the most challenging portion of the river within the park. This stretch, from Virginia Falls to Kraus Hotsprings is classified as grade II (medium). Rapids range from grade II in low water to grade IV (difficult) during high water. Canyon Rapids (grade III), Figure 8 Rapids (grade III/IV), George's Riffle (grade III), and Lafferty's Riffle (grade II/III) are the result of steep gradients and obstructions along the channel bed (Parks Canada 1979).

Ecology

The diversity and population levels of fauna in NNPR are a function of habitat which, in turn, is the result of physical factors such as climate, physiography, slope, soil and fire. For example, marshland habitats of the lower valleys support moose and beaver while upper valleys and the Ragged Range provide habitat for occasional woodland caribou and mountain goats respectively (Parks Canada 1983). Large mammal species such as Dall sheep, black bears, moose, and wood buffalo are subjects of nature photographers visiting the park.

Fire plays an important regeneration role in the boreal forests of NNPR and, as a result, the ages of forest stands differ throughout the park. Due to the rugged terrain, many fires burn rapidly across vast areas yet patches of land may be untouched; these patches act as refugia to recolonize the surrounding burn (Trottier 1985). Although approximately two fires per year are started by lightning strikes, climate conditions largely determine forest fire frequency.

While fires promote ecosystem sustainability by creating new habitat and recycling nutrients, they also create management problems. Imbalances in the natural fire regime can alter the proportions of vegetation and, subsequently, relative abundance of wildlife species (Trottier 1985). With regard to visitor safety, fires are hazardous because of the associated smoke and heat, and the potential for rapid spreading.

Visitor Use and Recreational Activities

The visitor season of NNPR is largely determined by the hydrological characteristics of South Nahanni River. Currently, it is concentrated from May to September with the majority of visitors frequenting the park in July and August after South Nahanni River has peaked and when weather is most pleasant.

The dominant recreational activities are water-based, and include canoeing and rafting. Land-based activities such as visiting historical sites, wilderness camping, hiking, nature photography and mountain climbing are typically secondary activities. Although overnight visitors normally stay in the park for a minimum of one week, approximately half (700) of the total visitors per year fly to Virginia Falls for one day and participate in land-based activities.

Climate Change Scenarios

Output from four climate change scenarios, three of which were derived from general circulation models (GCMs), was used to determine the potential changes in climate for NNPR. The Canadian Climate Centre (CCC) GCM, the General Fluid Dynamics Laboratory (GFDL) R30 GCM, the Goddard Institute for Space Studies (GISS) GCM and a composite model based upon a combination of paleoclimate data, instrumental data, and spatial analogs, were used in this study.

Estimated Temperature and Precipitation Changes

Each climate change scenario indicates that average monthly temperatures will increase every month, with the largest increases occurring in the winter. According to the CCC model, the mean annual temperature of the Nahanni basin may increase up to 4.2 degrees, the GISS model suggests it may increase 4.6 degrees, while the GFDL GCM and composite model output are the most conservative, with increases of 3.7 and 3.5 degrees Celsius, respectively. In general, each scenario suggests monthly precipitation may increase most months. The GFDL GCM suggests total annual precipitation may increase 40 percent. The CCC and composite models project increases in total precipitation of 12 percent and 10 percent respectively, while the GISS model suggests a two percent increase.

Interpreting Scenarios

For each of the four climate change scenarios, estimated temperature changes are significant enough to shift the climate of NNPR from a Cold Snowy Forest Climate (Dcf) to a Cold Forest Climate (Dbf) under Koppen's climate classification scheme and from a Boreal Climate (E)

to a Temperate Climate (Dcbf) under Trewartha's scheme (Trewartha 1968). Changes to the precipitation regime under the four climate change scenarios are not sufficient enough to alter moisture classifications.

Findings

Hydrological Impacts for the South Nahanni River

Changes in runoff for the South Nahanni River basin under a doubling of CO2 were derived from models developed by Soulis *et al.* (1994). The projected monthly runoff for the basin differs slightly among the three scenarios chosen for detailed analyses (GFDL and CCC GCMs, and composite scenario). However, despite differences in annual and some monthly runoff values among the models, projected runoff values for the summer months are similar for each model and resemble current conditions (**Figure 4**).

Recreational and Economic Impacts

The execution of water-based activities in NNPR under various climate change scenarios is based upon changes in seasonal temperature and precipitation patterns and the alterations in the hydrology of South Nahanni River. Under 2x CO2 conditions and considering only hydrological factors, the park could support a recreation season of nearly six months, extending from river break-up in early May to freeze-up in early November. However, as most visitors prefer to run the river after the peak discharge period, it is likely that paddlers will begin using the park in late June, and May will remain the spring shoulder season. July and August are expected to remain popular months for river running due to relatively high temperatures and stable weather.

Although climate-induced changes to river hydrology could affect the skills required for river recreation, it appears that the hydrological conditions of South Nahanni River under a doubling of CO2 will have little impact upon recreational activities within NNPR. Since future discharge levels in the summer months may resemble current ones, the classification of rapids along the Nahanni may not change: high levels of expertise may be required to navigate through the Figure 8 Rapids or George's Riffle.

In terms of economic implications, the Deh Cho region, the tourist area in which NNPR is located, may have an extended visitor season associated with climate change. The potential economic impact of an increase of four weeks in the visitor season can be estimated based upon a visitor survey by Robinson (1992). In this study, the average visitor expenditure was multiplied by the potential number of visitors for September for each visitor group. The potential number of visitors during this extended season is 450 and is based upon the assumption that future September visitation levels may be similar to current August levels. With average expenditures of approximately $2 098 for overnight visitors and $1 025 for day users, nearly $700 000 per year in additional revenue is possible.

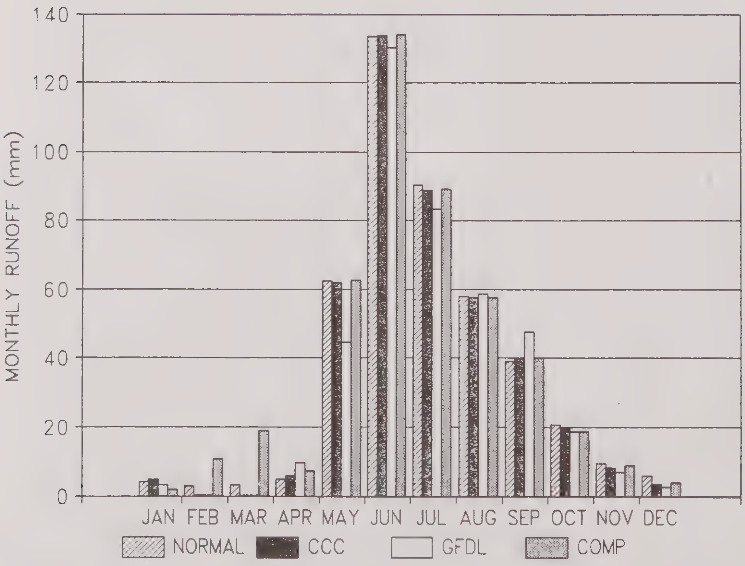

Figure 4. Estimated Runoff Changes for the South Nahanni Watershed under present and future climate conditions. Based upon Soulis et al. (1994).

Ecological Impacts

It is expected that for each one degree Celsius rise in average temperature, Canada's ecological zones will shift northwards 100 km (Curran 1991). Rizzo and Wiken (1992) determined the shifts in ecoclimatic provinces at a national scale under the GISS scenario of climate change. Black spruce stands may be displaced by mixedwood forests, balsam fir, white pine and white spruce, which characterize the cool temperate province (Environment Canada 1989). Although changes in faunal species and distribution were not included in Rizzo and Wiken's work, nor in this study, it can be stated that any shifts in a particular vegetation type would result in simi-

lar shifts in faunal species which live in or feed on that vegetation. Therefore, under the GISS scenario, ecological conditions currently existing in NNPR are likely to change if temperatures rise. However, human factors such as urban development, and agricultural and forestry practices may influence northward species movement.

Altitudinal shifts in life zones under $2xCO_2$ conditions may also occur in NNPR. Assuming that for every one degree increase in mean annual temperature, ecological communities shift between 100 and 150m in elevation (Wein *et al.* 1990), lifezones in NNPR may shift between 350m and 700m in altitude. In NNPR, a change of 350m may push nival and alpine habitats off high mountains in the Ragged Range, as well as subalpine habitats off other mountains in the western portion of the park. As few human barriers exist in the mountains, altitudinal shifts of vegetation zones may be more prevalent than latitudinal responses.

Shifts in ecoclimatic zones may have indirect effects upon recreational activities within NNPR. The seasonal discharge patterns of the South Nahanni River could be impacted indirectly through changes in evapotranspiration which, in turn, could affect rapid classifications and the white-water experience. Activities such as landscape viewing and nature photography may differ in the future as different plant and wildlife species may exist in the park.

Impacts upon Forest Fire Regimes

Under enhanced CO_2 conditions, more fires may occur due to lower water tables and a greater frequency of lightning. As increases in the frequency of extreme events can accelerate the response of forest vegetation to climate change (Wein and Hogg 1990), it is possible that changes in the forest fire regime may result in alterations in vegetation distribution and assemblages. In addition, if forest fires become severe enough to result in NNPR's closure, the length of the visitor season may decrease.

Adaptive Management Strategies for NNPR

Park managers are responsible for maintaining the ecological integrity of natural ecosystems through the management of biophysical elements and visitor activities. In the context of climate change, two strategies are proposed to respond to uncertainty; these allow park managers to remain adaptive in light of changing conditions.

First, the implementation of an ecological monitoring program within NNPR could serve several purposes: it would initiate and/or complete the collection of baseline data for various ecosystem components such as climate, and it could function as an early warning system by detecting deviations from the norm. The program could be used to assess the ecological integrity of the park for State of the Park Reports and could be used to monitor the environment surrounding the park. An ecological monitoring program could also identify trends associated with changing environments, thereby assisting park officials in making management decisions.

Second, implementing a monitoring program for human activities in NNPR could help to reduce the uncertainties associated with environmental change. As visitors are encouraged to develop an appreciation of the natural processes and cultural heritage of the park through participation in recreational activities, the health and sustainability of ecosystems will depend, in part, on the effective management of visitor use.

BATHURST CARIBOU STUDY

Objectives

The specific objectives for this study were to assess the possible implications of climate change for the Bathurst caribou herd, the herd being an important food resource for indigenous people and a major quarry for local recreational and visiting tourist hunters.

Methods

Data sets derived from general circulation models (GCMs), and a spatial analog with an historical climate data set, were used as sources of climatic information. A series of computer simulation models were modified for use with data available for the Bathurst herd of caribou and were employed to predict the energy, growth and population dynamics of the herd. The model output provide information on the size, and sex and age structure of the herd based upon changes in survival and pregnancy rates. These changes corresponded to modifications in environmental conditions associated with a changed climate. The climate change scenarios and the caribou simulation models were used to estimate the number, health, accessibility, and demographic characteristics of the Bathurst herd which, in turn, have implications for hunting of the herd.

The Bathurst caribou herd exhibits migratory behaviour throughout the year. The migratory patterns of the herd have been determined, and the areas used by the herd throughout the year have been ascertained. The winter range is used for approximately five months of the year (November to March), and eleven grid points were used to represent it. The spring route to the calving grounds (the area on which cows give birth) is used for the month of April, and ten grid points were used to represent it. The

calving grounds are used for approximately two months, May and June, and nine grid points represent them. The post-calving grounds are used in July and August, and eight grid points represented them, while the route to the winter range is used in September and October; nine grid points represented the former and ten represented the latter.

Periods in the annual life-cycle of the Bathurst caribou reflect the condition of the herd and the herd's activities. Based on work by Russell (1993a) for the Porcupine herd of Grant's caribou of the Yukon Territory and Alaska, the 15 periods in the life-cycle of the Bathurst caribou herd were determined.

The results obtained from the application of the climate change scenario output were interpreted based on the condition, location, and activities of the herd at various times throughout the year. As well, the possible effects of the climate changes for insect activity and snow conditions were determined. The former is highly dependent on air temperature, while the latter is affected by both air temperature and form and amount of precipitation.

A series of computer simulation models had been developed to predict the energy, growth, and population dynamics of the Porcupine herd of caribou (Daniel 1993). These models are interrelated; the energy model simulates a cow's metabolizable energy intake (MEI) over 15 annual life-cycle periods using various input data. This model predicts the effects of specific environmental conditions on MEI. The activity budgets within the model are set for each of the 15 life-cycle periods and are provided for different insect harassment and snow accumulation levels. The growth model evaluates the effects of changes in seasonal activity budgets and MEI on the energetics and reproductive status of a female caribou (Daniel 1993). This model evaluates the effects of the cow's energy balance on the growth of her fetus during pregnancy and her calf during lactation. The population dynamics model links the pregnancy rates and survival of the population to the weight of cows. This model tracks the dynamics of cohorts of caribou with similar characteristics.

A limited amount of data are available pertaining to the Bathurst caribou herd which can be used to convert the Porcupine caribou model into a Bathurst model. Where data are not available, changes were not made in the model. Data for a herd whose range is near that of the Bathurst herd were used as substitutes. Specifically, data for the Beverly herd of barren-ground caribou, whose range is southeast of the Bathurst's, were used. There is some winter range overlap of these herds and breeding occurs between the herds. Data pertaining to the Beverly herd that were used included mortality rates and population structure statistics (Thomas and Barry 1990a, 1990b).

The population model was run, incorporating the data available to convert it to a Bathurst caribou model. Corresponding to the changes suggested by the four climate change scenarios, the effects of different levels of insect harassment on MEI and the effects of changes in winter severity were determined.

An underlying concern in using the computer simulation models as developed for the Porcupine caribou herd is that the Porcupine and Bathurst herds are different caribou subspecies. This fact makes it necessary to emphasize that caution be used in interpreting the results of the computer model runs.

Findings

Four climate change scenarios were applied to the 57 grid points representing the locations of the Bathurst caribou herd. The CCC GCM suggests average monthly temperatures may increase each month up to 8.5 degrees, with the greatest warming possible in the winter. Moderate changes in precipitation are possible. The GFDL GCM suggests variability in average monthly temperatures and precipitation amounts may occur, with both increases and decreases from the 30-year normals. The composite scenario suggests precipitation may increase ten percent each month and monthly average temperatures may increase each month up to six degrees. The GISS transient GCM suggests variability from decade to decade in average monthly temperatures and precipitation amounts. Decreases in total monthly precipitation for some grid points are possible each month.

Snow depths were increased in the computer simulation models by ten and 20 percent, and insect harassment of the herd was intensified. Runs of the models suggest the total herd population may be 90 percent of that possible with current, average conditions, in ten years, and 81 percent in 20 years, if snow depths increase ten percent. The percentages if snow depths increase 20 percent are 79 and 62, respectively. The computer models suggest the proportion of the herd that is sexually mature and of breeding age may decrease. The proportion of bulls in the herd may increase for the two-to-six-year old classes, but decrease for the older classes. If snow depths increase and insect harassment increases, the amount of MEI may decrease during the winter, spring and summer seasons. In addition, the amount of vegetation consumed during winter, spring, and summer may decrease.

Implications

An increase in snow accumulation in the winter months may make the detection of food by caribou more difficult, and increase the time and energy needed to dig craters (to reach the vegetation beneath snow cover, caribou dig craters with their hooves). It is likely that as snow depths increase, caribou would spend more time looking for food, and less time feeding; in consequence, under-nutrition may occur.

Increased snow cover may increase caribou vulnerability to wolf attack, since snow acts as a physical hindrance to escape (Nelson and Mech 1986). In addition, the reduced mobility of caribou which inhibits the search for food and the increased energy costs of travel in deep snow reduce caribou fat reserves. The hunting success of wolves generally increases in deep snow unless the snow is very soft; therefore, the wolves' kill rate may increase as snow depth increases. In addition, when energetic expenditure by wolves is reduced, low utilization of kills has been reported to occur, since prey are presumably abundant and easy to kill (Fuller 1991).

An increase in snow depths at some grid points during November may disrupt the Bathurst caribou herd in its migration to the winter range, resulting in a smaller proportion of the herd wintering on the southernmost portion of the winter range. If fewer caribou migrate as far as Great Slave Lake, there may be fewer animals available to hunters in nearby communities, such as Rae-Edzo, Detah and Yellowknife. Hunting occurs in late fall near Great Slave Lake, and in December and January from the winter roads; however, hunters may be unsuccessful at this time. It would be necessary for those in southern communities to travel farther north to locate caribou.

The most nutritious vegetation appears immediately after snowmelt, and is in optimum condition for approximately six weeks (Russell 1993b). Because of the limited time that vegetation is in peak condition, it is important that the Bathurst herd maximize its use of the vegetation. While the herd may leave the winter range earlier than currently if snowmelt begins earlier, it is important that snowmelt also occurs at an appropriate time on the areas to which the herd is migrating. Adult females experience their largest energy deficit during the peak of calving (June 5 to June 12); it is crucial that they have access to highly nutritious vegetation at this time. Therefore, while early snowmelt would be beneficial early in spring, it could be detrimental by mid-June when energy and nutrient requirements are greatest (Russell 1993a).

Due to prohibitive hunting regulations and the poor condition of the animals, little hunting of the Bathurst herd occurs in the months of April, May or June. However, it is important that the herd be in good condition before, during, and after the calving period in June. It is questionable if weak, under-nourished caribou can regain enough of the weight which was lost during the spring months, in time for the fall hunt. The consequences of caribou not regaining weight would be detrimental for both the health of the herd and the hunters of the herd.

The summer months are very important for the health and condition of caribou, with the peaks in energy intake and energy requirements coinciding in early July. At the same time that caribou are at their lowest physical ebb in August, insect harassment is a problem from approximately the end of June until nearly snowfall. Warble flies, nasal bots, mosquitoes and black flies are the insects which harass the Bathurst caribou herd. It is possible that insect harassment may begin earlier, intensify, and last longer than currently, if the projections of the climate change scenarios are accurate. Warble flies and nasal bot flies may become a problem earlier in June than currently, since the climate change scenarios suggest average monthly June temperatures may increase. Mosquito activity may peak earlier, and last longer than currently, since the scenarios suggest average July monthly temperatures may increase. Mosquito activity normally decreases in August, when temperatures decrease; however, the climate change scenarios suggest average August monthly temperatures may increase at most grid points. These greater temperatures may cause mosquito and black fly harassment to intensify and last longer. The reduced energy intake that may occur from a possible increase in insect harassment may make it difficult for calves to grow adequately and make it difficult for bulls to gain enough of the fat reserves which are used during the fall rut. Mortality of bulls and calves in the following winter may thereby increase and pregnancy rates of females could decrease. In the long term, a decline in pregnancy rates may lead to lower birth rates for the herd and a decrease in herd size.

It is important that sufficient vegetation exists for caribou consumption in August. The search for adequate vegetation may result in a change in the Bathurst herd's range, thereby altering the location of the herd during the fall hunting season. Changes in the location of caribou may pose a problem for hunters, until the herd's new locations and migration patterns are known. The range of the herd may also decrease if herd size decreases, possibly making the herd less accessible to hunters.

Rain early in winter may cause vegetation to be cov-

ered in solid ice throughout the winter, if air temperatures decrease soon after rainfall. Solid ice covering vegetation has led to declines in populations of Peary caribou and muskoxen between 1961 and 1974 on Queen Elizabeth Islands (Diamond 1990). Precipitation falling as rain in October, followed by low air temperatures and snowfall, could cause a similar problem for caribou of the Bathurst herd.

It appears that the possible changes in October temperature and precipitation amounts may have positive effects for the Bathurst caribou herd. For some grid points, snow may not fall until November, so the herd may not encounter snow at all during its migration to the winter range. This would be beneficial, since energy that is currently spent moving about in snow, or cratering in the snow for vegetation, could instead be used to build up winter fat reserves.

Although the possible effects of climate change in October for the Bathurst caribou herd appear to be positive, it is important to note that the possible increases in intensity and duration of insect harassment in the summer may result in caribou of very weak condition. There may not be enough time, or enough vegetation, to enable caribou, particularly male caribou which are preferred by hunters, to regain fat reserves in time for the peak hunting activity in September and October. In addition, the range and distribution of the herd may change, if feeding habitats and population dynamics of the herd change: until the range of the herd can be determined, hunters may be unsuccessful, or less successful, in their activities.

If total snowfall increases in winter, the regions used by caribou of the Bathurst herd may change, since caribou do move in response to snow depths. The three recognized wintering areas may change as the herd seeks shallower snow depths. If hunters are not able to find caribou, negative effects may result for some sport hunting operations until wintering patterns of the herd are known and can be determined with some degree of certainty. Once wintering patterns of the herd can be ascertained, hunting expeditions can be planned more effectively and greater success in shooting caribou can be expected.

Overall, it appears that the effects of climate change may be detrimental to the Bathurst caribou herd. The most critical time period for the development and survival of the animals is June 5 to August 10: the importance of areas with few predators and abundant forage at this time cannot be overemphasized. The months of June and July are the time of highest energetic demands of lactating females, young calves and bulls. However, the problem and detrimental effects of insect harassment are expected to increase.

Management Options

Only two of the possible effects of climate change can be regarded as positive; these are early snowmelt in spring and the reduction or elimination of snowfall in October. Responding to and managing the possible effects of climate change for the Bathurst caribou herd will be difficult, since there is little agreement on the timing and magnitude of changes possible. One of the objectives of the Department of Renewable Resources of the NWT is the assurance that caribou are accessible and available to traditional users; this study suggests that this objective may not be met if the climate changes. Caribou may not be accessible to hunters in the southern communities of the animals' range and may be greatly reduced in number. One component of wildlife management is the establishment of priorities for objectives; due to the cultural and historical importance of caribou hunting for native people in the NWT, it is suggested that priority might be given to actions and policies which maintain the native harvest.

One management option that may be considered as a consequence of the possible effects of climate change is the imposition of limits on hunting of the Bathurst caribou. This could be done either through a reduction in the bag limit (currently, resident hunters may shoot up to five caribou; non-resident and non-resident alien hunters may shoot any number of males, in accordance with the number of tags held), or through a reduction in the time period that hunting is permitted (residents may hunt between August 15 and April 30, while non-residents may hunt between August 15 and November 30). It is uncertain which option hunters would be more willing to accept, or which would bring the greater amount of compliance.

If limits on hunting are adopted, it is important that communication with the public occurs; without public support, programs will meet with limited success. Hunters of the Bathurst caribou herd must understand that limits could be placed on hunting, if the health and numbers of the herd decline; such limits are meant to ensure that future deterioration of the herd does not occur. In the NWT, the communication challenge is compounded by the diversity of the languages in use and by the isolation of communities (Hall and Lloyd 1989). The Department of Renewable Resources has helped organize Hunters and Trappers Associations in nearly every community, to ensure that channels of communication exist. The involvement of native people in wildlife management is essential because they

form a majority of the NWT's population and because wildlife is vital to their culture and economy. One possibility is the formation of a Bathurst Management Board, similar to the Beverly and Kaminuriak Management Board, which is involved in the management decisions regarding the Beverly and Kaminuriak caribou herds (Hall and Lloyd 1989). Currently, decisions on the management of these herds and their habitat are not made without consulting the board, which consists of native users from communities on the herds' range. The formation of a Bathurst Management Board would ensure the involvement of user groups by providing a public forum for debate over any proposed management changes. Wildlife managers must ensure that people understand laws and the reasons behind them, since law enforcement is costly and difficult in the vast, sparsely-populated North. The formation of a Bathurst Management Board could enable the Department of Renewable Resources to meet another of its objectives, by involving the public and wildlife organizations in research and management decisions and strengthening public support for the conservation of caribou (Department of Renewable Resources 1988).

Interest in caribou by resident and non-resident naturalists continues to grow. In the future, it may be possible to separate the naturalist interest from other interests by using more refined management zones and seasons. The critical question is how caribou will be shared so that all needs can be met. This issue has been partially addressed by the various land claims agreements, which make it clear that the domestic needs of traditional users have top priority (Hall and Lloyd 1989).

Conclusions

Tourism is an important part of the economies of the Mackenzie Basin and NWT. It involves a diversity of both consumptive and non-consumptive activities which, in turn, are based to a great extent on a diversity of natural resources. These resources have the potential to be modified by climate change and this could result in changes in the experiences available to visitors. This study has shown that biological, economic, social and cultural repercussions of a changing climate may result for the Bathurst caribou herd, river recreation in NNPR, and the people which depend upon and use both. The water-based recreational activities available in NNPR are likely to remain largely unchanged and the season may even be extended slightly with positive economic implications although the environment in which they occur may be modified. In contrast, the resource base for hunting may be curtailed resulting in growing competition between residents and visitors for the use of an increasingly scarce resource. Although it is dangerous to generalize from two case studies, it is tempting to suggest that non-consumptive experiences which are dependent upon a general wilderness setting are less likely to be adversely affected than consumptive activities which rely upon a more specific resource such as a particular species.

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Settlements in the Mackenzie Basin: Now and in the Future 2050

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Overview

Our role within the Mackenzie Basin Impact Study (MBIS) was to study settlements and to create a global warming impact scenario. To accomplish these two goals, our study had two distinct components. The first component examines historic changes in the population size of these settlements. Our methodology was to create a settlement population data base for all communities recorded in the Censuses of Canada from 1941 to 1991. We then examined the pattern of population change over time for each urban centre. This approach allowed us to classify settlements by population change and to better understand how the size of these settlements might change in the future.

The second component speculates on the possible impact on these settlements caused by the melting of ice in permafrost due to global warming and the emergence of a thermokarst landscape. Since the Geological Survey of Canada (GSC) was studying permafrost in the Mackenzie Valley, we relied on the GSC for information about the extent of permafrost and the amount of ground ice in particular surficial materials. At the time of this study, the most current published data on ground ice by surficial deposits had been prepared by Dr. Alan Heginbottom (1995).

In our analysis of settlements in the Mackenzie Basin, we identified three types. These are Service Centres, Resource Towns and Native Settlements. Each has different functions and consequently strikingly distinct population growth patterns. In our final reports (Bone and others 1995 and 1996), we discuss these functions, population changes and implications for future growth in considerable detail. We also created a "permafrost subsidence" scenario based on a rise in air temperatures of 2°C. This scenario recognizes that proportion of ground ice varies by surficial material. In turn, this permits a geographic measure of the maximum potential subsidence by surficial material. Since the surficial geology and ground ice map prepared by Heginbottom is at a scale of 1:7.5 million, its application to settlement sites in the Mackenzie Basin represents a first-order generalization.

In our presentation at the Final Workshop of MBIS, we elected to present a summary of our findings, emphasizing resource towns. For this paper, however, we have added a scenario of possible impacts of ground subsidence on the other settlements. A detailed account for Native Settlements, Service Centres and Resource Towns is available in the Settlement Report submitted to Dr. Stewart Cohen in December 1995 (Bone and others 1995).

Settlements in the Mackenzie Basin

The Mackenzie Basin contains nearly half a million people. Because of the sparsity of agricultural land and its frontier economy, most resident live in one of the 132 settlements found in the Mackenzie Basin. In terms of an urban and transportation hierarchy, Edmonton serves as the major metropolitan centre for the region — though Edmonton is not located in this basin.

Table 1. Frequency Distribution by Settlement Size, 1991.

Community Size	Mackenzie Basin		North of 60		South of 60	
	No.	%	No.	%	No.	%
> 30,000	1	0.8	0	0.0	1	1.0
10,000 - 29,999	4	3.0	1	2.8	3	3.1
5,000 - 9,999	6	4.5	0	0.0	6	6.2
1,000 - 4,999	28	21.2	5	14.3	23	23.7
500 - 999	26	19.7	9	25.7	17	17.5
100 - 499	41	31.1	10	28.6	31	32.0
< 100	26	19.7	10	28.6	16	16.5
Totals	132	100	35	100	97	100

Source: Census of Canada 1991 Cat. 93-304

One of the most striking characteristics of these 132 settlements is their small population size. To a large degree, this is a reflection of the region's dual economies. In the case of the Native economy, small settlements are associated with a hunting economy, while in the case of the industrial economy, small centres normally predominate in the economic periphery. In the Mackenzie Basin, for example, nearly 20% of its urban centres have less than 100 residents and 70% have less than 1000 residents. At the same time, there is no metropolitan city located in this hinterland. In fact, the largest centre, Fort McMurray, only has a population of 35,000.

A second characteristic is the different types of settlements in the Mackenzie Basin. For the purposes of this paper, they have been classified into three types. These are Resource Towns, Service Centres and Native Settlements.

Of the three types of urban places, Native Settlements are the most common, followed by Service Centres and, finally, Resource Towns. Almost all of the places with a population under 100 persons are Native Settlements while only Service Centres and Resource Towns have communities with populations exceeding 2,000 inhabitants.

Table 2. Settlements by Type, 1991

Type	Size	#	Min. Size	Max. Size 1991
Resource Towns:	N/A	12	None	34,706 Ft. McMurray
Service Centres:	Major	7	> 5000	28,271 Grande Prairie
	Medium	23	1000 to 5000	4,719 Westlock
	Minor	24	< 1000	3,842 Grande Cache
Native Settlements:	Large	16	> 500	1,521 Rae Edzo
	Medium	29	100 to 500	485 Ft. Liard
	Small	21	< 100	94 Jean Bapt. 183 R
Total:		132		

***Note:** Uranium City was classified as a Resource Town until 1981. Now it is classified as a Native Settlement. In 1961, Yellowknife was classified as a Resource Town. Now it is a major Service Centre.

A third characteristic is the demographic difference between southern and northern parts of the Mackenzie Basin. The North, defined as those lands lying north of the 60th parallel, accounts for less than 10% of the basin's population but just over 25% of the number of settlements. The explanation for this geographic variation is that a much higher proportion of settlements with less than 100 residents are located in the North than the South. The term "tiny" is applied to settlements with less than 100 residents. In **Table 1**, the North has nearly 29% of its settlements falling into the tiny category while the South has only 16.5%. In both the North and South, almost all of these villages are Native Settlements.

Resource Towns in the Mackenzie Basin

Resource towns are defined as having one dominant economic function, resource extraction. Of the 132 urban centres recorded by Census Canada in 1991, we classified only 12 as resource towns. These resource centres are identified in **Table 3**.

Single-industry towns, however, tend to be larger than Native Settlements and most Service Centres. In 1991, the total population of Resource Towns was 71,500, forming 30% of the settlement population. In comparison, the population of Native communities comprised 8% of the urban population.

Table 3. Resource Towns, 1991

Resource Towns: (12)	Prov.	CD	Total Pop.
Pine Point	NWT	FSR	9
Norman Wells	NWT	IR	627
Rainbow Lake	AB	17	817
Taylor (DM)	BC	55	821
Hudson Hope (DM)	BC	55	985
Chetwynd (DM)	BC	55	2843
Barrhead	AB	13	4160
Tumbler Ridge (DM)	BC	55	4650
Mackenzie (DM)	BC	53	5542
Edson	AB	14	7323
Hinton	AB	14	9046
Ft. McMurray	AB	16	34706

Source: Census of Canada

Types of Resource Towns

Based on theory and empirical evidence, we have classified resource towns into four categories. The first three types are based on non-renewable resources and therefore have a fixed life span — unless they can diversify. The fourth type of resource town is based on a renewable resource. In all cases, this resource was commercial forest stands. These are:

- Classic boom-bust towns
- Towns of uncertainty
- Diversified towns
- Renewable resource towns.

Classic Boom-Bust Towns

Classic boom-bust towns refer to those single-industry mining towns that have completed their life cycle. From our investigation, such towns undergo three phases in their population growth. These phases are illustrated by the changes in populations of the mining towns of Pine Point in the Northwest Territories and Uranium City in northern Saskatchewan. The population data are from the Census of Canada. The three phases are:

- Rapid population growth
- Stabilization
- Rapid population loss

After the mine at Pine Point closed, the community lost its population, public institutions and service firms. Without the mine, Pine Point had no raison d'etre. By 1991, Pine Point no longer existed as a community. Unlike Pine Point, Uranium City continues to function but at a greatly scaled down operation. Like Pine Point, the miners

and their families left the community. The difference between the two places is that Uranium City also had a small Indian and Métis population. When the mine closed, most of these residents decided to stay. Within a year following the closure of the mine, Uranium City changed from a resource centre of 2,000 inhabitants to a Native Settlement with about 150 persons. This sudden transformation to either a ghost town or a Native Settlement is a common characteristic in the life-cycle of non-renewable resource towns located in remote areas of northern Canada (**Figure** 1).

Towns of Uncertainty

Towns of uncertainty are also single-industry mining towns. They, however, have not completed their life-cycle and, as a result, still have an opportunity to broaden their economic base. If successful, such centres could take on another economic life after the ore body is exhausted. Two examples are Fort McMurray, an important heavy oil extraction and processing centre in northern Alberta, and the oil producing centre of Norman Wells in the Northwest Territories.

Fort McMurray is a large town of nearly 35,000. While size is an advantage, Fort McMurray is far from other population centres, making it difficult for the town to develop a regional service role. If the heavy oil industry were to cease operations, Fort McMurray would undergo a dramatic downsizing. While its complex urban infrastructure is a decided advantage for its long-term survival, its location poses problems for diversification. The massive size of its heavy oil reserves and the technological advances leading to lower production costs suggest that this resource town's future is secure for the time begin (**Figure 2**).

Norman Wells exists as an oil extraction centre. It has a very small population — less than 700 persons. Like Uranium City, downsizing is inevitable when oil production ceased. Because of its infrastructure, Norman Wells could remain a small service centre, acting as a transshipment point for surround communities. Since its housing stock and sewer and water system are much superior to that found in neighbouring Native communities, Norman Wells could attract families from neighbouring settlements. If Esso Resources discontinued its operations at Norman Wells, the entire Esso labour force would be reassigned to positions in other Esso operations. The unknown question is whether or not the community could hold on to its service and transportation functions.

Diversified Towns

Yellowknife represents an outstanding example of a mining town that diversified into a rapidly growing regional centre. All of this became possible when Yellowknife was selected as the capital of the Northwest Territories. As a mining town, however, Yellowknife suffered from the population fluctuations common to other such towns. In 1936, Yellowknife began its existence as an unplanned mining camp on the shores of Great Slave Lake. Over the next 30 years, the centre's economic life and population size rose and fell in accordance with the price of gold. These population fluctuations are illustrated in **Figure 3**.

In 1967, Yellowknife embarked on an expanding economy and population. This change was due to the fact that Yellowknife was chosen as the capital of the Northwest

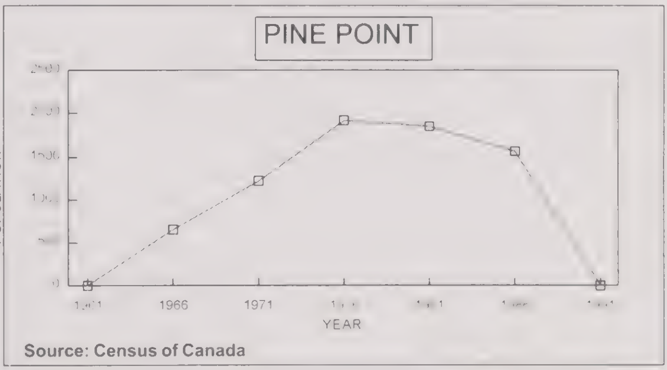

Figure 1.

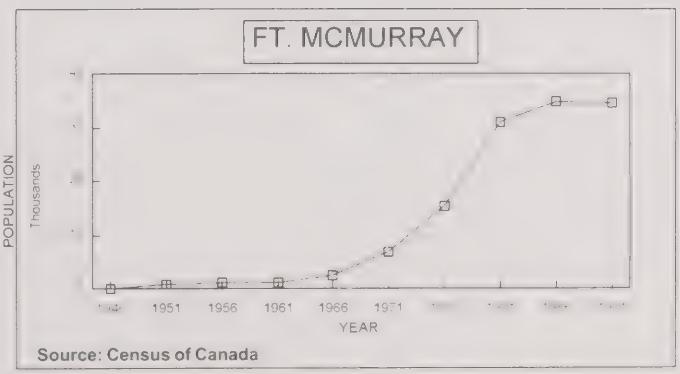

Figure 2.

Territories. Until that time, almost all the public agencies and departments serving the Northwest Territories were located in Ottawa and Fort Smith. With the selection of Yellowknife as the new capital, Ottawa transferred many federal units to Yellowknife, creating both a new service function and a large in-migration of well-paid civil servants and their families. The spending power of these newcomers created the basis for larger construction and private service sectors. Also, Yellowknife has attracted many Aboriginal families and individuals because of the prospects for employment and because of the wider range of urban amenities. Since 1967, Yellowknife has experienced a steady increase in its population (**Figure 4**).

In the future, Yellowknife faces both the possibility of business expansion and administration contraction. Economic expansion could come with the construction and then operation of one or more diamond mines near Lac de Gras some 200 km northeast of Yellowknife. Because Yellowknife is ideally situated to serve as a labour and materials supply depot for such mines, a new influx of workers and their families is a possibility.

On the other hand, the division of the Northwest Territories in 1999 into two territories, each with their own government, could see the transfer of roughly one-third of the administrative functions now in Yellowknife to Iqaluit, the designated capital of Nunavut. The magnitude of this administrative transfer will have a severe impact on the population of Yellowknife not only because of the loss of administrators and their families but also because of the secondary effects on the rest of the economy. The net result could see a reduction in Yellowknife's population.

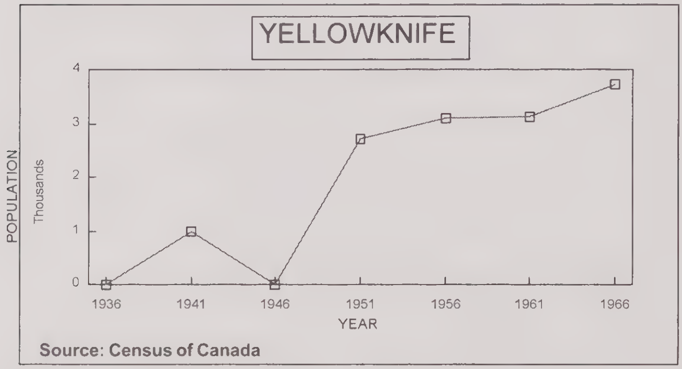

Figure 3.

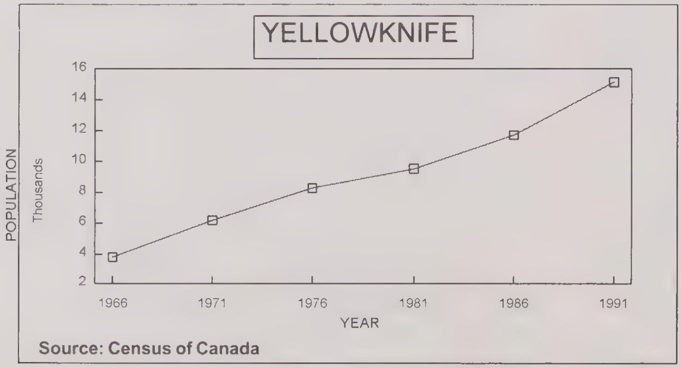

Figure 4.

Renewable Resource Towns

Unlike mining towns, communities based on renewable resources do not face the inevitable exhaustion of their natural wealth. This difference between renewable and non-renewable resources represents a fundamental division among resource towns. With a sustainable resource management strategy, single-industry communities based on a renewable resource can avoid the relatively short life-cycle associated with most mining towns. In the Mackenzie Basin, forestry provides the foundation for such a sustainable economy.

Our examination of two industrial centres based on the forest resource towns confirmed this concept. In the two lumber towns of Chetwynd and Mackenzie, their population grew rapidly with the establishment of sawmilling firms and then stabilized (**Figure 5**). Another population surge could occur if further processing of timber occurred. Chetwynd provides an example of this second population surge following the construction of pulp and paper plant in the late 1970s. Based on the same wood resource but now but now utilizing trees unsuitable for lumber production and the waste products from sawmilling, the new mill had a sufficient raw material source. Renewable Resource Towns, therefore, have the potential to expand their economy and thus undergo additional population surges.

Classification of Permafrost and Ground Ice

Global warming, permafrost and ground ice provide the basic ingredients for a scenario describing the potential subsidence of the land in the Mackenzie Basin. The essential infor-

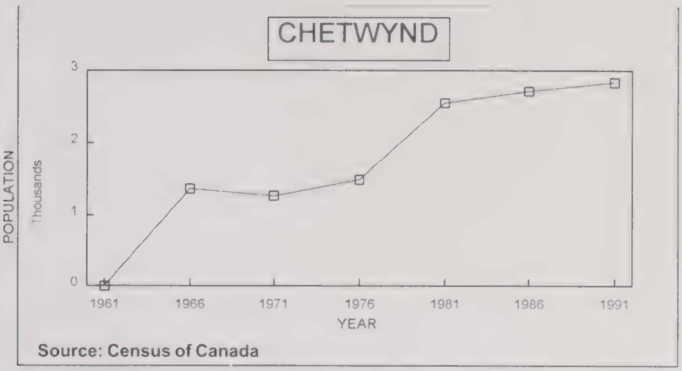

Figure 5.

mation on permafrost and ground ice was derived from the permafrost map prepared by Dr. Alan Heginbottom. Permafrost consists of four types — continuous permafrost, extensive discontinuous permafrost, sporadic discontinuous permafrost and isolated patches of permafrost. This classification is based on the proportion of ground that is permanently frozen in a geographic area. For example, in the continuous permafrost zone, permanently frozen ground exists in at least 90% of the area. This percentage decreases for each of the following permafrost types. For example, the presence of permafrost in the zone classified as having extensive discontinuous permafrost falls below 90% but remains above 50%. Generally, this incremental decrease occurs in accordance with increases in mean annual temperatures. Within the Mackenzie Basin, mean annual temperatures are much lower north of the 60th parallel and this fact is reflected in the type of permafrost. For instance, the extensive discontinuous permafrost zone is much more extensive north of the 60th parallel. For the same reason, the sporadic discontinuous permafrost zone, defined as having permafrost between 10% and 49% of its land area, lies almost entirely south of the 60th parallel. The final type of permafrost is found exclusively in the southern half of the Mackenzie Basin. In fact, it acts as a transition zone between permafrost and non-permafrost areas. Here, only isolated patches of permanently frozen ground are found, making up less than 10% of its area.

Ground ice is normally found in the upper 20 metres of the ground. The percentage of ground ice varies within that 20 metres, depending on the surficial geology. Some surficial materials can hold more moisture than others. On the basis of this notion, Heginbottom has assigned a certain percentage of ground ice to each type of surficial material. To simplify the problem of assigning values of ground ice to different materials, Heginbottom has created four general categories. They are described as areas with high, medium, low, or zero amounts of ground ice. A site classified as having a high content of ground ice would have more than 20% of its subsurface containing ground ice. An area with between 10 and 20% would be described as having a medium content. An area with less than 10% but with some sign of permafrost would fall in the low group.

In **Table 4**, the code for the capital letter symbols is C = continuous permafrost; E = extensive discontinuous permafrost; and I = isolated patches of permafrost. The lower case letter symbols are h = high content of ground ice; m = medium content of ground ice; l= low content of ground ice; and n = no ground ice.

Scenario Year 2050: Global Warming, Permafrost and Resource Towns

Global warming may have many effects on the physical landscape of the Mackenzie Basin. In our global warming scenario to 2050, we assume that the rise in air temperatures will melt the ice found in the sporadic and discontinuous permafrost and greatly thicken the active layer in the continuous zone of permafrost. In this hypothetical world, considerable subsidence of the ground would occur, resulting in an irregular landscape known as thermokarsk topography. Localized subsidence could cause considerable damage to buildings, roads and other facilities in settlements. Subsidence may also affect highways, power lines and pipelines. Since the proportion of ice in frozen ground varies by the type of surficial material, communities situated on ice-rich terrain would be subject to high levels of ground subsidence.

Surficial deposits that have a high capacity to hold moisture often contain large amounts of either fine grained materials rich in clay and silt, or organic materials. In the continuous permafrost zone, ground ice may comprise over half of the volume of these surficial materials. In some places, this percentage can reach over 80%. In other places within the continuous permafrost zone, terrain with a low content of ice is found. Bedrock, for instance, contains virtually no ice. In the Mackenzie Basin, the Canadian Shield provides numerous examples of ice-poor terrain in both the continuous and discontinuous permafrost zones.

In our examination of Resource Towns, we found that two communities are located outside of the perma-

frost zone while others lie within the permafrost zone but in ice-free locations. Combined, these two groups of towns form nearly 60% of the Resource Towns in the Mackenzie Basin.

Approximately 40% of the Resource Towns are located in extensive discontinuous permafrost zone. These centres may be affected by subsidence caused by the melting of ground ice. Since the proportion of ice in permafrost varies by the type of surficial material, certain communities are more likely to be subjected to ground subsidence than other settlements.

Table 4. Resource Towns: Potential Subsidence

Resource Towns: (12)	Prov.	Total 1991 Pop.	Permafrost Types	Ground Ice (% volume)
Pine Point	NWT	9	Sl	< 10
Norman Wells	NWT	627	Em	10 - 20
Rainbow Lake	AB	817	Sl	< 10
Taylor (DM)	BC	821	In	0
Hudson Hope (DM)	BC	985	In	0
Chetwynd (DM)	BC	2843	In	0
Barrhead	AB	4160		0
Tumbler Ridge (DM)	BC	4650	In	0
Mackenzie (DM)	BC	5542	Inl	< 10
Edson	AB	7323		0
Hinton	AB	9046	In	0
Ft. McMurray	AB	34706	Inl	< 10

Source: Census of Canada and Heginbottom 1995.

With that in mind, single-industry towns have been ranked with Norman Wells assigned the greatest potential for subsidence (**Table 4**). The four rankings found in **Table 4** are associated with the percentage of ground ice in the substrata near these resource towns. Those sites with over 10% ground ice are rated 1; those with less than 10% but more than zero are rated 2; and those with no signs of ground ice but lying within a permafrost zone are rated 3. Those single-industry towns located outside the permafrost zone are rated zero. While both the last two types of sites contain no frozen ground, their rankings are different. The reason is that one is situated in the permafrost zone and the others are not.

Norman Wells is the most vulnerable resource community in term of potential ground subsidence. This oil-town is situated in the zone of discontinuous permafrost. It is located on an alluvial terrace with a high ice content. Because of these two factors, Norman Wells is more likely to suffer from ground subsidence than other resource towns. In a more detailed investigation of ground ice, Burgess, Desrochers and Saunders (1995) support this notion. They analyzed the data from several drill cores in the Norman Wells area. Using this more precise information on ground ice, they prepared three possible thaw depth increases under a 2 X CO_2. The increase in the active layer ranges from 1/2 metre to 2.5 metres. While the actual ground ice content is not known, if we assume that 50% of the volume is ground ice, then the subsidence could range from 1/2 metre to 1.25 metres.

Ground Subsidence Scenario for all Communities

In this section, the hypothetical subsidence of land in the Mackenzie Basin caused by global warming is applied to the remaining types of settlements, namely Native Settlements and Service Centres. The purpose is to indicate that the potential for ground subsidence varies widely across the Mackenzie Basin. As before, the assumption is that most subsidence would occur in the areas where ice-rich ground is found. The data on the estimated percentage of ground ice were derived from Heginbottom's permafrost map. Unlike Resource Towns, a number of Service Centres and Native Settlements are situated at sites where ice-rich ground is found. Therefore, the potential risk from extreme ground subsidence is higher among these two categories of settlements. Equally important, the resulting thermokarst topography could have a negative impact on transportation routes leading to these centres.

While acknowledging that the data produced by Heginbottom are highly generalized for application to precise geographic points, the use of the permafrost and ground ice units described in **Table 4** generates a first order classification of subsidence by settlement sites. The 16 permafrost/ground ice units devised by Heginbottom are assigned subsidence values based on the proportion of ground ice estimated to occur in the ground. High risk sites are associated with surficial material where over 20% of the volume of this material to a depth of 20 metres contains ground ice while those with between 10% and 20% are rated as medium risk sites (**Table 5**). Theoretically, global warming could induce subsidence exceeding 4 metres at high risk sites.

Concluding Remarks

The potential impact of Global Warming on settlements in the Mackenzie Basin has many ramifications. In this paper, we explored one such ramification, namely the possible impact of ground subsidence and the resulting formation of thermokarst topography on settlements in the Mackenzie Basin. Under our scenario, the basic conclusion is that the vast majority of the 132 communities in the Mackenzie Basin are located in the zone of isolated

Table 5. Settlement Sites of Medium and High Risk Subsidence

Medium Risk Communities	High Risk Communities
Aklavik	Arctic Red River
Colville Lake	Fort Good Hope
Detah	Fort McPherson
Fort Franklin	Tuktoyaktuk
Fort Norman	
Inuvik	
Nahanni Butte	
Norman Wells	
Rae-Edzo	
Rae Lakes	
Reliance	
Snare Lake	
Snowdrift	

patches of permafrost or are outside of the permafrost zone. These communities should not be at risk. However, four communities — all Native communities — fall into a high risk category. They are Arctic Red River, Fort Good Hope, Fort McPherson and Tuktoyaktuk. Another thirteen centres form a medium risk group. With the formation of thermokarst topography around these high and medium risk communities, their transportation routes may also be at risk.

By initiating an interdisciplinary study, the Mackenzie Basin Impact Study has explored many facets of research not likely to have been tackled on their own. Our study certainly falls into that category for without the information supplied by GSC, our work would have been impossible. With the ongoing permafrost research by the GSC, including their forthcoming GSC Atlas of the Mackenzie Valley and their continuation of ground ice research, a more detailed and precise geographic account of permafrost is emerging. With such information, a more refined account of a Global Warming/Subsidence scenario will be possible.

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8

INTEGRATED ASSESSMENT MODELS

Integrated Climate Change Impact Assessment and Sustainable Land Use: The Mackenzie River Basin

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This paper focuses on one approach of the integrated phase of the MBIS project, the integrated land assessment. Since the Mackenzie Basin is essentially a natural resource based economy and resource sectors are most vulnerable to climate change, understanding the impacts of climatic change on the land use system is crucial to sustainable economic development of the region.

A conceptual research framework of the integrated land assessment framework (ILAF) is presented briefly. The focus is on how the ILAF approach was applied to the Mackenzie River Basin for climate change impact assessment. Different operations research methods are adopted as decision support for impact assessment and policy evaluation. These include goal programming (GP) and multi-criteria decision making (MCDM) such as AHP.

Applying the Integrated Approach to the Mackenzie Basin

The Integrated Land Assessment Framework (ILAF) for MBIS

A conceptual integrated land assessment framework (ILAF), which is part of the integrated phase of the Mackenzie Basin Impact Study (MBIS), has been presented in detail in Yin and Cohen (1994a). The main elements of the ILAF are illustrated in Figure 1. The main structure of the ILAF is purposely kept general and is mainly composed of several types of methods or techniques. First, a multi-criteria decision making (MCDM) technique, the analytic hierarchy process (AHP) developed by Saaty (1980), was used to identify goals and their priorities. AHP can provide means by which alternative goals could be compared and evaluated in an orderly and systematic manner.

Second, remote sensing image processing technology was used for collecting and updating land cover and land use information. Application of satellite image processing in climate change impact study can facilitate the process of data collection and the measurement of land use changes. Timely updated information about the regional resource base is essential for analysis. Specific computer software technologies for satellite image processing were developed to extract, enhance, and classify digital image.

Third, a geographic information system, SPANS, was employed to incorporate various data sets from different resource sectors such as wildlife, forestry, and agriculture. The SPANS can perform efficient storage, retrieval, and manipulation of spatial data.

Fourth, three types of scenarios were specified: climate change, socio-economic, and adaptation options to global warming. These scenarios were used to examine their economic-environmental impacts.

Fifth, various simulation models were employed by several individual projects of the Mackenzie Basin Impact Study (MBIS) to study the first and second order impacts of climate change scenarios (Cohen, 1994).

Sixth, an analytical system was developed for climate change impact assessment and policy evaluation. The analytical system was the core of the ILAF. Goal programming (GP) method was used to build the system.

The first five components or steps of the ILAF system have been discussed in detail elsewhere (Yin and Cohen, 1994a; 1994b). The following application focuses on how the GP model was used to conduct the integrated climate change impact assessment. The application sought to provide answers to some questions in relation to climate change. Major questions examined were: what are the implications of climate change for achieving regional development goals? Does climate change increase land use conflicts among different resource sectors? If potential conflicts are identified, how serious might they be? What are the possible trade-offs for alternative response policies to climate change?

The Study Area

The ILAF was applied to the Mackenzie River Basin in Canada. The basin is located in the northwest part of Canada and is the largest river basin in the country. Accordingly, to reflect the interregional and spatial considerations in the assessment, the Mackenzie Basin is partitioned into sets of sub-regions. The sub-basins corresponding to critical zones of the Mackenzie Basin are illustrated in Huang et al. (1996), Figure 2, in this volume. Sub-regions

1, 3, 6, 8, 9, 10,11, 14, 15, 19, and 21 are included in the integrated analysis.

Data Sources and Land Use Sectors

Data required for the integrated impact assessment come from several sources: existing data derived from previous studies on land resource analysis and management, government documents, consultant reports, and scientific literature. Huang et al. (1996), and Hartley and Marshell (1996) provided data for forest sector. Stumpage rates and annual allowable cut (AAC) data were derived from Rothman and Herbert (1996). Crop yields data were derived from studies conducted by Brklacich et al. (1996) and Yin and Pierce (1993). Please refer to the chapters by the authors respectively in this report. Information of the soil loss coefficients or soil loss rates by water erosion for each crop in each land unit was not available from existing sources and therefore was calculated by using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). This computation was based on a report completed by Van Vliet (1989), which provided the values of key factors of the USLE. Soil erosion rates for cropland, pasture, woodland, and summer fallow for each sub-region were calculated and were used in the soil erosion control goal constraint.

It is obvious that the sources of data for the integrated impact study are diverse and extensive. Such data sources are often limited for integrated impact assessment by inconsistencies in scale and coverage and definition. The data inconsistencies pose problems of comparability. For example the scale used by Huang and others was sub-basin, while the forest impact study by Hartley and Marshell adopted a much finer scale. Consistent and comparable data sets would improve the reliability of the integrated impact study.

Yin et al. (1994) presented an integrated database for the integrated impact study. Data required for coefficients of various activities include prices of products, costs of production, average yields, areas of different types of land, soil erosion rates and wetland values. The data collected also have spatial and temporal dimensions. The model variables and parameters differ among sub-regions, and vary between the present and the future (changed climate condition). Thus, the database consists of information for each sub-region under both current and future conditions (**Tables 1–5**). Considering impact data on forests were only available for the GISS scenario, the GP model was run under current and GISS scenarios.

The information collected was sorted into sub-regions and land use activities. Economic activities considered for each sensitive sector are consistent to those selected for sectoral analyses. These activities are represented in the model by decision variables. The model is flexible enough to incorporate other variables for assessment. With limited data provided by MBIS individual projects, three sectors are selected in the GP model: the agriculture, forestry, and wetland. Land use activities considered for the agricultural sector include wheat, barley, oats, canola, hay, and summer-fallow. These crops and forage might be only grown in certain sub-regions based on climate conditions. The activities in the forest sector include timber productions of spruce, lodgepole pine, and deciduous trees. Wetland habitat value was based solely on waterfowl numbers.

The Basic Model Structure

The GP model provides a means for coordinating resource assessments made by different sectors which represent various components of a rural land use system. For the integrated model, intersectoral relationships need to be incorporated in the structure of the model by a clear articulation and reconciliation of objective functions and decision variables. The basic structure of the GP model adopted

Table 1. Coefficients for different activities in different sub-regions of the Mackenzie Basin (current condition).

Sub-regions	1	3	4	8	9	10	13	14	16	20	21
coefficient											
Wheat yield coeff. (t/ha)	0.00	0.00	2.30	0.00	2.30	2.80	3.30	3.20	2.80	3.10	2.80
Barley yield coeff. (t/ha)	0.00	0.00	2.10	0.00	2.50	2.50	3.60	3.10	4.80	3.20	3.10
Oats yield coeff. (t/ha)	0.00	0.00	2.30	0.00	2.35	2.54	3.86	3.15	3.85	3.65	3.25
Hay yield coeff. (t/ha)	0.00	0.00	3.80	0.00	3.36	3.80	3.80	4.47	5.38	5.38	3.80
Canola yield coeff. (t/ha)	0.00	0.00	0.00	0.00	0.00	0.74	0.91	0.89	1.11	0.89	0.89
Spruce yield coeff. (m3/ha)	1.43	1.31	1.65	1.43	1.98	1.98	2.05	2.03	2.20	1.90	2.50
Lodgepole pine (m3/ha)	1.26	1.11	1.53	1.26	1.83	1.98	1.95	1.95	2.17	1.80	2.40
Deciduous tree (m3/ha)	0.86	0.72	1.19	0.86	1.51	1.50	1.68	1.50	1.50	1.55	1.40
Wetland habitat coeff. (bird)	0.55	1.41	5.62	0.24	0.49	1.50	1.25	0.92	0.91	2.21	0.91

Table 2. Net economic return coefficients (current condition).

Sub-regions	1	3	4	8	9	10	13	14	16	20	21
Wheat production ($/ha)	0.00	0.00	40.10	0.00	82.35	102.20	127.00	107.00	132.00	112.00	107.00
Barley production ($/ha)	0.00	0.00	22.96	0.00	20.13	29.83	40.50	39.83	40.20	39.85	32.85
Barley on converted land ($/ha)	0.00	0.00	12.29	0.00	12.96	14.50	23.90	24.55	26.35	24.55	21.25
Oats production ($/ha)	0.00	0.00	27.10	0.00	28.13	29.83	40.50	34.50	40.20	38.00	35.00
Hay production ($/ha)	0.00	0.00	44.80	0.00	42.40	44.80	44.80	48.30	52.10	52.10	44.80
Hay on forest converted ($/ha)	0.00	0.00	29.30	0.00	26.55	29.27	29.27	34.20	38.05	38.05	29.27
Hay on wetland converted ($/ha)	0.00	0.00	30.60	0.00	27.78	30.62	30.62	35.30	39.39	39.39	30.62
Canola production ($/ha)	0.00	0.00	0.00	0.00	0.00	73.46	180.00	137.70	232.97	137.70	137.70
Spruce timber production ($/ha)	54.57	50.00	63.00	54.60	75.56	75.56	78.23	77.46	83.95	72.50	95.40
Lodgepole-pine timber ($/ha)	21.53	18.97	26.10	21.50	31.27	33.84	33.33	33.33	37.09	30.76	41.00
Deciduous timber ($/ha)	4.50	3.75	6.20	4.48	7.87	7.82	8.75	7.82	7.82	8.08	7.29

Table 3. Soil erosion rate coefficients (t/yr) (for current condition and GISS scenario).

Sub-region	1	3	4	8	9	10	13	14	16	20	21
Wheat	0.0	0.0	10.9	0.0	6.6	15.4	15.4	11.7	5.8	14.1	11.7
Barley	0.0	0.0	10.9	0.0	6.6	15.4	15.4	11.7	5.8	14.1	11.7
Oats	0.0	0.0	10.9	0.0	6.6	15.4	15.4	11.7	5.8	14.1	11.7
Hay	0.0	0.0	1.8	0.0	1.1	2.6	2.6	2.0	1.0	2.4	2.4
Canola	0.0	0.0	0.0	0.0	0.0	15.4	15.4	11.7	5.8	14.1	14.1
Summer fallow	0.0	0.0	22.0	0.0	22.0	38.9	51.4	38.9	51.3	46.9	46.9
Spruce	0.7	0.7	0.8	0.7	0.3	0.5	0.6	0.3	1.5	1.2	1.5
Lodgepole-pine	0.7	0.7	0.8	0.7	0.3	0.5	0.6	0.3	1.5	1.2	1.5
Deciduous	0.7	0.7	0.8	0.7	0.3	0.5	0.6	0.3	1.5	1.2	1.5

Table 4. Coefficients for different activities in different sub-regions in the Mackenzie Basin (GISS scenario)

Sub-regions	1	3	4	8	9	10	13	14	16	20	21
coefficient											
Wheat yield coeff. (t/ha)	0.00	0.00	1.75	0.00	1.75	2.13	2.51	2.44	2.13	2.36	2.13
Barley yield coeff. (t/ha)	0.00	0.00	1.72	0.00	2.05	2.05	2.95	2.54	3.93	2.62	2.54
Oats yield coeff. (t/ha)	0.00	0.00	1.88	0.00	1.92	2.08	3.16	2.58	3.15	2.99	2.66
Hay yield coeff. (t/ha)	0.00	0.00	3.80	0.00	3.36	3.80	3.80	4.47	5.38	5.38	3.80
Canola yield coeff. (t/ha)	0.00	0.00	0.42	0.00	0.42	0.74	0.89	0.91	1.11	0.77	0.74
Spruce yield coeff. (m3/ha)	0.72	0.66	0.83	0.72	0.99	0.99	1.03	1.02	1.10	0.95	1.25
Lodgepole pine (m3/ha)	1.26	1.11	1.53	1.26	1.83	1.98	1.95	1.95	2.17	1.80	2.40
Deciduous tree (m3/ha)	1.55	1.30	2.14	1.55	2.72	2.70	3.02	2.70	2.70	2.79	2.52
Wetland habitat coeff. (bird)	0.55	1.41	5.62	0.24	0.49	1.50	1.25	0.92	0.91	2.21	0.91

Table 5. Net economic return coefficients (GISS scenario)

Sub-regions	1	3	4	8	9	10	13	14	16	20	21
Wheat production ($/ha)	0.00	0.00	30.51	0.00	62.66	77.75	96.60	81.59	100.41	85.26	81.40
Barley production ($/ha)	0.00	0.00	18.81	0.00	16.51	24.46	33.19	32.63	32.91	32.63	26.92
Barley on converted land ($/ha)	0.00	0.00	12.29	0.00	12.96	14.50	23.90	24.55	26.35	24.55	21.25
Oats production ($/ha)	0.00	0.00	22.15	0.00	22.98	24.43	33.16	28.26	32.89	31.13	28.65
Hay production ($/ha)	0.00	0.00	44.80	0.00	42.40	44.80	44.80	48.30	52.10	52.10	44.80
Hay on forest converted ($/ha)	0.00	0.00	29.30	0.00	26.55	29.27	29.27	34.20	38.05	38.05	29.27
Hay on wetland converted ($/ha)	0.00	0.00	30.60	0.00	27.78	30.62	30.62	35.30	39.39	39.39	30.62
Canola production ($/ha)	0.00	0.00	29.25	0.00	29.25	73.46	176.04	140.79	232.97	119.13	114.49
Spruce timber production ($/ha)	54.57	50.00	63.00	54.60	75.56	75.56	78.23	77.46	83.95	72.50	95.40
Lodgepole-pine timber ($/ha)	21.53	18.97	26.10	21.50	31.27	33.84	33.33	33.33	37.09	30.76	41.00
Deciduous timber ($/ha)	4.50	3.75	6.20	4.48	7.87	7.82	8.75	7.82	7.82	8.08	7.29

in the ILAF includes goals and constraints. The specific equations of the model are grouped into following types: resource and other restrictions, supply-demand balances, goal constraints, and the objective function. A simple formation of the goal programming model designed for this study are expressed as following :

$$\text{Min.}\ Z = [g_1(d^-, d^+,), g_2(d^-, d^+,), \ldots, g_k(d^-, d^+)] \quad (1)$$

Subject to:

$$\sum_p x_{pj} + \sum_i x^{\otimes}_{ij} - \sum_i x^{\otimes}_{ji}\ le\ A_j \quad (2)$$

$$\sum_p \sum_j (R_{pj} * x_{pj}) + \sum_p \sum_i \sum_j (R^{\otimes}_{pij} * x^{\otimes}_{pij}) + d^-_r - d^+_r = b_r \quad (3)$$

$$\sum_p \sum_j [Y_{pj} * (x_{pj} + \sum_i x^{\otimes}_{pij})] + d^-_y - d^+_y = b_y \quad (4)$$

$$\sum_p \sum_j [E_{pj} * (x_{pj} + \sum_i x^{\otimes}_{pij})] + d^-_e - d^+_e = b_e \quad (5)$$

$$\sum_c \sum_j (V_{cj} * x_{cj}) + d^-_v - d^+_v = b_v \quad (6)$$

$$x,\ x^{\otimes},\ d^-,\ d^+\ ge\ 0 \quad (7)$$

Where: Z is the objective function or achievement function of the integrated model, which is to minimize the non-attainment of defined target levels; $g_k(d^-, d^+)$ is a linear function of the deviation variables at priority level k = 1,2,...,k; x is area of land use; x_{pj} is the area of land use *p* in sector *j;* $x^{\otimes}$ is land conversion variable; $x^{\otimes}_{ij}$ and $x^{\otimes}_{ji}$ are two decision variables representing respectively land areas converted from sector *i* to *j*, and land areas converted from sector *j* to sector *i;* $x^{\otimes}_{pij}$ is area of land use *p* on converted land (from sector i) in sector *j;* A_j is resource availability for sector *j;* R_{pj} is net return for land use *p* in sector *j;* $R^{\otimes}_{pij}$ is net return from converted land (from other sectors *i*) for land use *p* in sector *j;* Y_{pj} is yield of land use *p* in sector *j;* E_{pj} is soil erosion rate of land use *p* in sector *j;* x_{tj} is tree species *t* in sector j; $x^{\otimes}_{tij}$ is land converted from sector i to j for tree (*t*) planting; x_{cj} is the area of wetland class *c* in sector *j;* V_{cj} is the habitat value for waterfowl capability class *c* in sector *j;* b_y, b_r, b_e and b_v are the right-hand-side vector representing the target values for goals *y, r, e,* and *v* (resource production, economic return, soil erosion, and waterfowl habitat) respectively; d^+ and d^- are the overachievement and underachievement vectors of goal target levels respectively.

Two technical aspects were created to achieve the integration. First, intersectoral relationships are established by development of an integrated model structure. Second, the creation of conversion variables, coordinating constraints, and joint goal constraints in the integrated model makes the integration of the three resource sectors possible. The integrated model represents the combined land use systems of agricultural, forestry, and wetland sectors in a region. The structure of the integrated model reflects interactions among resource sectors. The flow of land resources from one sector to another is an important feature of the integrated model, which provides a linkage among resource sectors. Shifting land use from one sector to another is also an important consequence of climate change.

Joint land constraints (2) which take account of land

conversion from one sector to another are created in the integrated model to coordinate various resource sectors. These inequalities (2) represent the fact that land resources used for various purposes in each sector are limited. The total land used by different resource sectors cannot exceed existing lands plus lands converted from other sectors and minus lands converted to other sectors.

To reflect resource flow between sectors (i.e. land use change) in the study region, conversion variables, $x^{\otimes}_{ij}$ and $x^{\otimes}_{ji}$ are created and incorporated in the integrated model for each land sector j. The conversion variables represent respectively land areas converted from other sectors i to sector j and from j to other sector i annually.

There are several algorithmic techniques that can be adopted to solve GP models. In this study, the Microsoft Excel Version 5.0 which runs on the PC486 environment, was used for solving problems in operations research.

Yin and Cohen (1994a) presents a systematic approach, assisted by AHP, to identify and specify regional development goals relating to climate change. The article shows the results of a survey which illustrates the regional ranking order of land use goals. The responses to the interviews are indicative of the diverse range of values associated with the real and perceived benefits to be derived from the land resource base. Due to large amount of uncertainty involved, considerable variation on goal ranking was experienced in the interviews. The aggregated goal preferences general patterns were used to assign priority ordering for the region. The interview results on regional priority ranking of goals were incorporated in the integrated land assessment framework to study the regional impact of climate change. In particular, the objective function of the GP model was set with the regional goal priority ranking.

Climate Change Impact Assessment

In this analysis, the ILAF was applied to indicate the impacts of climate change scenarios on the attainment of land use goals. One particular question addressed in this analysis is: do climate change scenario threaten sustainable crop and timber production, adequate economic return to the land resource base, reduction of soil loss by erosion, and preservation of waterfowl habitat?

Two scenarios were considered for the impact analysis of climate change. Scenario 1 is the base scenario for comparison, which represents the current condition. Scenarios 2 reflects the conditions under the GISS transient GCM result. As discussed in previous papers (Yin and Cohen, 1994a; 1994b), the ILAF was in the integrated phase of MBIS, and thus relied on data provided by other MBIS individual projects. The impact of climate change on forest sector was based on the GISS transient GCM scenario. The Mackenzie Basin Forest Productivity (MBFP) model was run with current and GISS transient GCM scenarios. To be consistent with that study and with other data restrain, the ILAF could only run the two scenarios at this stage.

The results of the two runs with the two scenarios are presented in **Table 6**. Under scenario 2, there are no significant changes in achieving net return and grain production goals compared with results for scenario 1. Climate change (GISS scenario) results in a moderate reduction in the attainment of spruce timber production, and a significant increasing of soil erosion in the Basin. This is due to the fact that declining crop and forest yields associated with climate change reduces the capacity of the region to achieve its timber production target and forces more land for grain production. As a result, soil erosion rates increased dramatically.

Response Policy Analysis

The multi-sector GP model could also be used for policy analysis to estimate the likely consequence of the potential policy on regional development goal achievement. This type of information provides a basis for planners or decision makers to determine the adequacy and effectiveness of the policy before it is implemented. In policy analysis, a potential response policy can be specified as a policy scenario. The policy can be represented in the model by adjusting the model parameters or structure. The aim of

Table 6. Results of the model runs under current and GISS scenarios (10^3).

		Wheat (t)	Barley (t)	Oats (t)	Hay (t)	Canola (t)	Spruce (m3)	Pine (m3)	Deciduous (m3)	Net return ($)	Soil erosion (t)	Habitat value (bird)
Basic Scenario	Goal Target	432	767	231	1517	350	1198	409	952	102015	43511	6663
	Deviation	0	0	0	0	0	0	0	0	0	0	0
GISS Scenario	Goal Target	648	1151	347	2276	525	1115	429	808	153022	43511	6663
	Deviation	0	0	0	0	0	-154	0	0	0	+10715	0

the response policy is to reduce negative impacts of climate change scenario.

A comparison of the results between policy scenario and scenario 1 would show the different goal achievements under the two scenarios. If the goal achievements are improved significantly under policy scenario, then the policy is assumed to be effective. A list of Alternative policy options can be evaluated to identify the desirable policy options. At this stage, no real run of the model for policy scenario was conducted yet.

Conclusion

In summary, the chief contribution of this paper is not so much to provide information or solutions for improving land use planning under climate change conditions. Rather, it is to provide procedures for integrating multiple resource use objectives (or indicators) and a range of resource sectors, in order to systematically investigate the impacts of climate change scenarios. In this sense the model developed is for heuristic purposes. The integrated land assessment model possesses characteristics of a learning tool and a means of communication. As such, the results presented in the case study should not be viewed as a final analysis of the issues in relation to climate change and response options.

Although an extensive endeavour has been made in modelling technology development, there are limitations in the integrated assessment system and thus there is room for improvement. For example, certain aspects of the land use system have not been addressed explicitly in the integrated land resource assessment system such as recreation, fishery, defence, and forestry wildlife activities.

Adjustments to the integrated assessment system could be undertaken by adding livestock activity to the agricultural sector, and adding wildlife habitat, recreation, and range use to the forestry and wetland sectors, as well as fishery and defence sectors in the models. At this point, data for these land use activities are either not available or insufficient for analysis. There are other mechanisms or marketing relationships which could be incorporated into the modular structure of the analytical system. The present structure of the assessment system consists of only land resource constraints. Labour, capital, and technology constraints are not considered in the assessment. Thus, it is assumed that labour and capital are not scarce resources in the study region. The incorporation of labour and capital resource constraints in the models would be helpful in studying land use problems from a different perspective.

This study only considered the GISS transient scenario. When impacts of other climate change scenarios are available in the future, the model can be run with additional results to provide further information. Land use shifting under climate change scenario was not studied by MBIS individual projects and thus was not included in the integrated assessment. Yin (1996) illustrates a systematic approach to take land use shifting under climate change into consideration in an integrated assessment.

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Integrated Modelling For Climate Change Impact Assessment In Mackenzie Basin

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Abstract

In this study, an integrated climate-change impact assessment for Mackenzie Basin, Canada, was conducted through development and application of an inexact multiobjective programming (IMOP) model. Many sectors, including agriculture, forest, wildlife habitat preservation, wetland preservation, hunting, recreation, soil conservation, non-point source pollution control and water resources development, as well as their interactive relationships, were considered and integrated within this study. The IMOP can reflect not only particular structure and entities of a complex system, but also processes, interactions and feedback mechanisms within the system that generate changes in its dynamics and structure. It also allows uncertainties to be effectively communicated into the optimization process and resulting solutions. The results indicate that, generally, temporal variations of land characteristics and thus land use activities exist due to changes in climatic, economic and environmental conditions. However, through effective systems analysis and assessment, the impacts of climate change could potentially be adapted and the desired land use patterns for compromising objectives from different stakeholders could thus be obtained.

Key words: *climate change, integrated modelling, multi-objective programming, inexact, uncertainty, systems analysis.*

1. Introduction

Much of Canada is located in high latitudes (north of 55° N), and there are concerns about possible effects of future climate changes. According to the Intergovernmental Panel on Climate Change (IPCC 1990a and b), high latitude regions are expected to have greater winter warming than the other parts of the world under the changing climate. Warmer temperatures would contribute to a rise in global sea level due to melting of ice and thermal expansion of oceans.

Mackenzie Basin is situated in northwestern Canada and is the largest river basin in the country. The basin includes parts of the Yukon and Northwest Territories as well as Northern British Columbia, Alberta and Saskatchewan (**see inside cover**). It has experienced a warming trend of 1.5 °C in this century. There is some evidence that this has lowered lake levels and thawed permafrost. The basin contains many different ecosystems (forest, wetland, delta, etc.) and several climate-sensitive transition zones, such as discontinuous permafrost, tree line, northern limit of agriculture and commercial forestry, deltas sensitive to water levels, and wildlife migration routes. These zones could be the early indicators of climatic change. It is important to learn as much about their potential sensitivities so that better information would be available for adaptation purposes. Also, the basin has essentially a natural resources based economy. A number of resource sectors are vulnerable to climate change (Cohen 1993 and 1994). Consequently, understanding the impacts of climate change on the resource use system is crucial to sustainable development of the region.

There has been little information on possible impacts of climate change in the north. Many questions remain to be answered, such as "what difference would climate change make to the regional economy?", "would forestry and agriculture expand northward?", "how would recreation and tourism be affected?", and "what would happen to northern communities?". Consequently, climate change impact studies would potentially help answering the above questions by providing information required by policy makers in developing more efficient response options to a changing climate and better management plans for the sustainability of our life-support system (Dzidonu and Foster 1993).

Due to complex and uncertain natures of the interactive relationships between different system components under changing climate, using an effective impact assessment approach seems desirable. The majority of the previous studies focused either on physical, chemical, biological, or economic aspects of climate change impacts individually, failing to recognize the importance of intersectoral relations (Rotmans et al. 1994). Researches which took a holistic viewpoint were relatively rare.

More recently, some integrated impact studies were undertaken. For example, Rotmans (1990) adopted a systems approach in designing a research framework, named IMAGE, to link modelling analysis with policy concerns for integrated climate change impact study. A well known

application of systems analysis approach to regional climate change impact assessment is the MINK study. Resources for the Future (RFF) adapted a systems analysis approach to study potential regional impacts of climate change and relevant response options, which was applied to four states (Missouri, Iowa, Nebraska, and Kansas). Estimates of the potential regional resource production and economic return under climate change scenarios were compared with those on present conditions to show regional economic impacts (USDOE 1991; Rosenberg 1992). Brklacich and Smit (1992) applied a linear programming model, LEM, to assess the effects of potential climate change scenarios on regional food production in Ontario.

However, most of the previous integrated studies were based on deterministic, single-objective or single-sector programming, which were not flexible for identifying and reflecting complicated interactions, conflicts, trade-offs, and uncertainties in a study system. In this respect, an inexact multiobjective programming (IMOP) technique is developed and applied to the climate change impact study in the Mackenzie Basin. The method will improve upon the existing fuzzy/stochastic multiobjective programming methods with advantages in data availability, solution algorithm, computational requirement and result interpretation (Huang 1996a).

Thus, the objectives of this study are (i) to investigate integrated climate-change impact assessment in the Mackenzie Basin, and (ii) to develop an IMOP model that can reflect the complex system features in the study area. Through the proposed IMOP, interactive relationships between different land-use activities and between different system objectives/constraints will be effectively reflected. Potential conflicts and relevant compromises will be highlighted. Thus, alternatives corresponding to different adaptation strategies can be generated through interpretation of the modelling outputs.

This study is part of the integrated phase of the Mackenzie Basin Impact Study (MBIS). Funded by the Government of Canada's Green Plan and other sponsors, the MBIS is a multi-year and multi-disciplinary research project to examine the regional impacts of projected global warming. The main purposes of the MBIS are to define the direction and magnitude of regional scale impacts of climate change scenarios on the physical, biological and human systems of the Mackenzie Basin, and to identify regional policy implications of these impacts (Cohen 1993).

2. System Complexity

The problem of a changing climate is not just about climate, energy consumption or emissions of greenhouse gases. The problem is also about the effects such a change will have on the earth's ecosystems, resources and human settlements, and about the need to reduce or avoid these effects. The character of Mackenzie Basin in the North is extremely complex, as a product of rapid socio-economic transformation resulting from the mix of traditional and "southern" technologies and associated world views. The pace of changes has remained very high in the last two decades, with rapid population growth rates and continued technological development. There are many biologically productive and culturally or socially valuable areas in the basin that could be affected by climate change. These include deltas, alluvial areas, wetland, wildlife habitats, and various areas of scenic, historic, or scientific value. A number of activities were undertaken in the basin, including mining, fossil fuel development and related infrastructure (such as pipelines), commercial fishing and tourism (including several national parks). Commercial forestry and agriculture are generally restricted to areas south of 60°N within the Liard, Peace and Athabasca Subbasins **(see map inside front cover)**. Agricultural operations are also located near Hay River of Northwest Territories (NWT), and some white spruce is harvested in the Yukon portion of the Liard Subbasin and the south part of the NWT (MRBC 1981). Aboriginal communities pursue traditional subsistence activities, such as hunting, fishing and trapping, but they are also looking to initiate development ventures in tourism, transportation and other activities. Land claims are currently being negotiated between native organizations and the federal government. It is expected that this will alter current resource management plans (Gibson 1990).

For each time period with given climate change scenario and environmental/economic conditions, there may be interactions and conflicts between different land use activities and between different system constraints/objectives. For example, climate change may lead to increase in tillable land area for agriculture, and thus affect the planning of agricultural activities; variation of prices for agricultural products may lead to changes in the design of land use patterns; also, agricultural land uses may cause long-term environmental/ecological degradation problems and affect recreational, transportational, and wildlife activities (**Figure 1**).

For the study time horizon, climate change impacts on regional economic, resources, and environmental subsystems may vary temporally with dynamic features (Dowlatabadi and Morgan 1993; Rotmans et al. 1994). For example, variations of climatic and socio-economic condi-

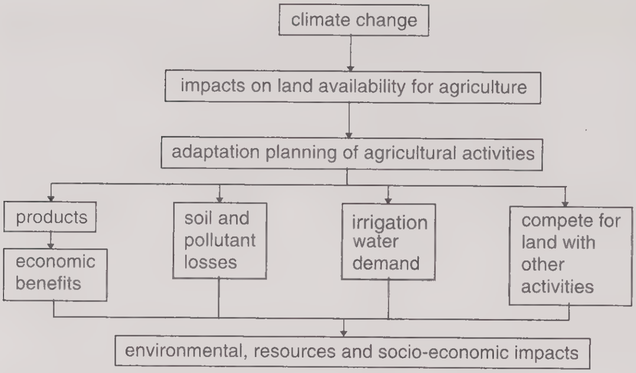


Figure 1. Intricate interactive relationships in agricultural subsystem.

tions over time may lead to changes in and thus conflicts between agricultural/timbering activities, and may need compromises between different stakeholders in order to obtain an overall optimal; Variation of prices for agricultural products may affect the planning of crop production levels; expansion of crop production may have impacts on forest cover (and thus timbering production) due to land use conflicts. Therefore, reflection of this temporal variation characteristic in systems analysis models would be important for generating effective and realistic assessment and adaptation results. Also, due to the possibility of continuous changes in system components along with time, it is suggested that the assessment and adaptation studies should lead to a "real-time" system. This means that the research results should be composed of not only a set of firm alternatives but also a controllable assessment system (Huang et al. 1996). Thus, environmental managers can use real-time information which they will obtain in the future periods to update the model inputs, and thus generate more realistic outputs for the farther periods.

The concept of uncertainty plays a key role in this research project because forecasting climate change and its consequences for human society is beset with many uncertainties. Many of the system components and their interrelationships may not be known with certainty but as follows: "the land area suitable for agriculture is between 40,000 and 50,000 ha", "the benefit of forest timbering in the region is about $10/ha", and so on. This makes the system more complicated and hard to be effectively quantified. Normally, people get used of using mean or middle value to represent uncertain information. However, for a system with many uncertain factors, this type of approach may lead to loss of information or significant errors. Thus, making the uncertainties visible and tangible and reflecting them effectively are important issues for this study.

It is obvious that, in the study system, there exist many environmental, socio-economic, and resources objectives related to a number of stakeholders with different interests. These objectives may have conflicts to each other. Thus, the problem is how to make tradeoff or compromise between interests from different stakeholders bearing different objectives, in order to maximize the general benefit of the entire system (i.e. the entire basin during the entire study time horizon).

The above discussion demonstrates the complexity of the study system. Simple decision process by direct analysis/assessment or expert consultation would not be good enough for effectively reflecting these complex characteristics. Therefore, development and application of suitable systems analysis approaches to integrate a variety of system components (objectives, constraints, and activities) within a general framework would be necessary for providing realistic assessment and desired adaptation planning.

3. Integrated Approach

An integrated assessment model is defined as a model that is designed to analyze the phenomenon of climate change from an integrated perspective. Integration means capturing as much as possible of information about the cause-effect relationships, cross-linkages, and interactions between various subsystems. Such an integrated modelling approach will enable the consequences of several types of human influences to be evaluated simultaneously.

For the Mackenzie Basin, a number of biophysical and socio-economic factors have to be considered due to their direct or indirect relations to the climate change (Yin and Cohen 1994). Integrated assessment will incorporate individual system components within a general framework rather than examine them in isolation. This would be useful for exposing interactions between individual sectors or study topics and providing holistic and comprehensive analysis of climate change impacts and their implications for achieving regional resource development objectives (Dzidonu and Foster 1993; Yin et al. 1995). An integrated approach, thus, should possess certain fundamental characteristics including: (a) able to ensure public participation, (b) systematic and comprehensive, (c) multiple objectives and multiple sectors, and (d) able to easily identify trade-offs. Based on the above consideration, the scopes

of this study are as follows.

(i) Many sectors, including agriculture, forest, wildlife habitat preservation, wetland preservation, hunting, recreation, soil conservation, nonpoint source pollution control, and water resources development, are considered and integrated within this study. Their interactive relationships are reflected through formulation of the IMOP model.

(ii) Many inexact scenarios of climate change impacts on land availability for different activities were generated by an interval analysis approach based on results from a number of MBIS subprojects and other available information.

(iii) To reflect interregional and spatial considerations in the assessment, the basin was further divided into twenty-one subareas with different environmental, economic and resources characteristics, corresponding to critical zones determined by MBIS Working Committee (**Figure 2**) (Cohen 1994). **Table 1** shows land area of the subareas.

(iv) The study time horizon was 50 years (1995 to 2045), which was further divided into seven planning periods (1995-2000, 2001-2005, 2006-2010, 2011-2015, 2016-2025, 2026-2035, and 2036-2045). Over the 50-year planning horizon, it was assumed that climate change would lead to impacts on socio-economic and biophysical sectors in the basin and thus affect different land use activities.

(v) The cost/benefit values in the IMOP are expressed in present value dollars. They are escalated to reflect anticipated conditions and then discounted to generate present value terms for the objective function. For example, for present value P, assuming that its future values (k years later) is F, we have the relation between P and F as follows:

$$P = F\,(1 + i)^{-10\,(k-1)}, \qquad (1)$$

where i is a discount rate.

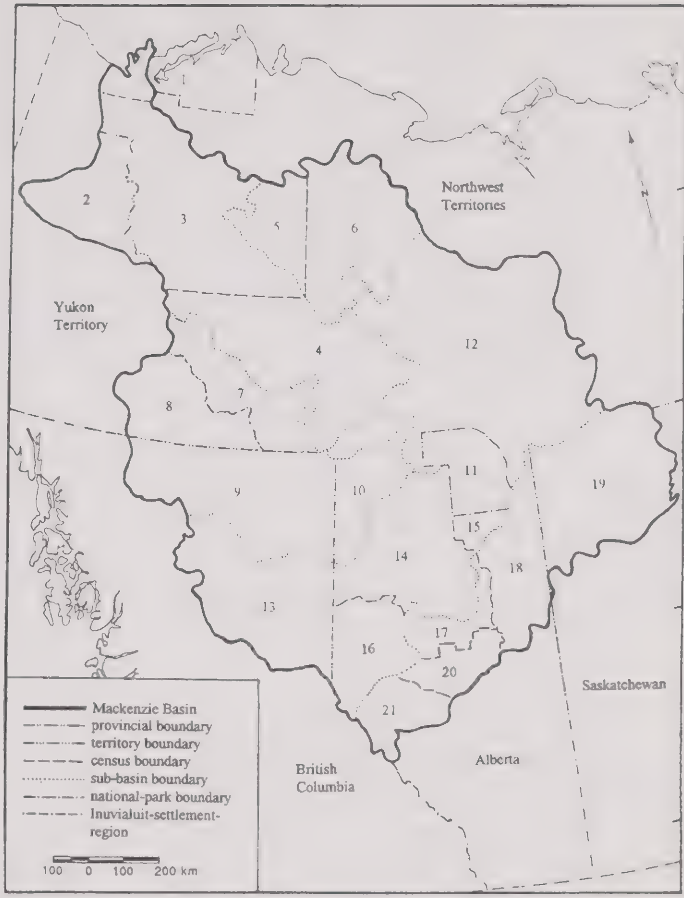


Figure 2. Distribution of the study subbasins and subareas.

Generally, information obtained based on the above scopes will be integrated within a general framework. This integration will enable the inclusion of interaction and feedback mechanisms and can therefore yield insights that scattered information cannot offer. Thus, it will provide decision-makers with a framework which can be used to choose a desirable course of action, or to predict the outcome of one or more courses of action (Rotmans et al. 1994).

4. Inexact Multiobjective Programming

The above facts emphasize that, in the assessment and planning processes, all related system activities should be considered as a general entity. A good scheme for one or several sectors may not be good for the entire system. Generally, climate change will affect the distribution of land suitability for different activities (e.g. potential and productivity for agricultural production). Thus, dis-

tion of land use activities should be adjusted to adapt the climate change impacts and obtain desired environmental/economic benefits.

Systems analysis approach is useful for integrating a variety of system components (objectives, constraints, and activities) with uncertain, interactive, dynamic and multiobjective natures within a general modelling framework. Previously, the majority of methods that deal with uncertainty in multiobjective optimization problems relate to stochastic multiobjective programming (SMOP) and fuzzy multiobjective programming (FMOP), where problems of data availability, solution algorithm, computational requirements, and results interpretation exist (Zimmermann 1978; Kunsch 1990; Urli and Nadeau 1990; Bit et al. 1993; Huang et al. 1996). One potential approach for mitigating the above weaknesses is through the introduction of the concepts of inexact analysis and inexact decision (Huang 1996a) into a multiobjective programming (MOP) framework. This would lead to an inexact multiobjective programming (IMOP) formulation. The IMOP model will be applied to the Mackenzie Basin for integrating results from individual studies of physical, biological, and socio-economic components within the MBIS to effectively reflect the complex system features and internalize the intricate interrelationships among a variety of system components. The IMOP will also be capable of yielding adequate information for the potential responses of different land use activities to climate change. The IMOP solutions can be compared to each other and to the present activities temporally and spatially in order to assess the impacts and finally generate desired adaptation strategies.

Table 1. Land area for the 21 subareas.

Subarea	Province	Subbasin	Land Area (1000 km^2)
1	NT	Mackenzie River Subbasin	16.7
2	NT	Mackenzie River Subbasin	61.5
3	NT	Mackenzie River Subbasin	139.7
4	NT	Mackenzie River Subbasin	128.1
5	NT	Great Bear Lake Subbasin	48.1
6	NT	Great Bear Lake Subbasin	72.9
7	NT	Liard River Subbasin	51.7
8	YT	Liard River Subbasin	62
9	BC	Liard River Subbasin	106.5
10	AB	Liard River Subbasin	43.9
11	AB/NT	Wood Buffalo National Park	37.9
12	NT	Great Slave Lake Subbasin	317.5
13	BC	Peace River Subbasin	115.8
14	AB	Peace River Subbasin	91.5
15	AB	Peace River Subbasin	12.2
16	AB	Peace River Subbasin	49.4
17	AB	Lake Athabasca Subbasin	32.9
18	AB	Lake Athabasca Subbasin	62
19	SK	Lake Athabasca Subbasin	123.7
20	AB	Lake Athabasca Subbasin	31.6
21	AB	Lake Athabasca Subbasin	34.8

NT = Northwest Territories   AB = Alberta
YT = Yukon Territory   SK = Saskatchewan
BC = British Columbia

Let x denote a closed and bounded set of real numbers. An inexact number $x^{\pm}$ is defined as an interval with known upper and lower bounds but unknown distribution information for x:

$$x^{\pm} = [x^-, x^+] = \{t \in x \mid x^- \leq t \leq x^+\}, \tag{2}$$

where x^- and x^+ are the lower and upper bounds of $x^{\pm}$, respectively. When $x^- = x^+$, $x^{\pm}$ becomes a deterministic number.

An IMOP model can be formulated as follows:

$$\textbf{Max} \quad [Z^{\pm}_1(\mathbf{X}^{\pm}), Z^{\pm}_2(\mathbf{X}^{\pm}), \ldots, Z^{\pm}_p(\mathbf{X}^{\pm})], \tag{3a}$$

$$\textbf{Min} \quad [Z^{\pm}_{p+1}(\mathbf{X}^{\pm}), Z^{\pm}_{p+2}(\mathbf{X}^{\pm}), \ldots, Z^{\pm}_q(\mathbf{X}^{\pm})], \tag{3b}$$

$$\textbf{s.t.} \quad g^{\pm}_i(\mathbf{X}^{\pm}) \leq b^{\pm}_i, \; i = 1, 2, \ldots, m, \tag{3c}$$

$$\mathbf{X}^{\pm} \geq 0, \tag{3d}$$

where $\mathbf{X}^{\pm}$ is an inexact vector of decision variables, $\mathbf{X}^{\pm} = \{x^{\pm}_j \mid j = 1, 2, \ldots, n\}$; $Z^{\pm}_t(\mathbf{X}^{\pm})$ are inexact objective functions, $t = 1, 2, \ldots, q$; and $g^{\pm}_i(\mathbf{X}^{\pm}) \leq b^{\pm}_i$ are inexact constraints, $i = 1, 2, \ldots, m$ (Huang et al. 1996).

Generally, the dynamic assessment and adaptation planning problem for the MBIS can be broken up into individual stages corresponding to the time intervals within the planning horizon. All the entire basin, the entire time horizon (50 years), and the interactions between different components are integrated within a general system. The inexact decision variables represent various land use activities in different spatial locations over the time horizon, as well as the dynamic characteristics of activity development decisions corresponding to the variations of land suitability due to climate change. The objective is to achieve optimal adaptation planning with desired environmental, economic and social goals. The constraints include all relationships between decision variables and climate change situations. Thus, an IMOP model for the study system can be structured as follows:

Maximize (or Minimize):

economic objective,
forest cover objective,

wildlife habitat preservation objective,
wetland preservation objective,
soil/pollutant loss objective,

subject to:

total land availability constraints,
agricultural production constraints,
forest and timbering constraints,
recreational activity constraints,
wildlife habitat preservation constraints
wetland preservation constraints,
livestock husbandry constraints,
water demand constraints,
soil erosion constraints,
water quality constraints,
technical constraints.

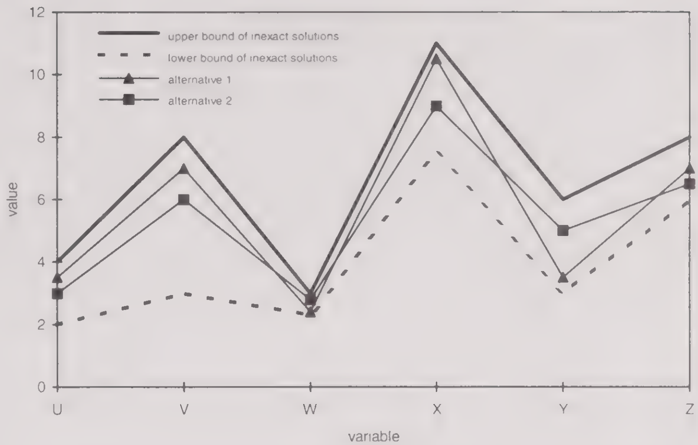


Figure 3. Example of generating two alternatives through a set of inexact solutions.

The detailed model is presented in Huang (1996b). The IMOP allows uncertainty to be directly communicated into the optimization process and provides solutions presented as inexact intervals. The modelling results can be used for generating decision alternatives by adjusting different combinations of decision variable values within their solution intervals (**Figure 3** gives an example of generating two alternatives based on a set of inexact solutions. Actually, many more alternatives can be generated through interpreting the solutions). Thus, a number of questions regarding activities at the initial time stages and throughout the study horizon can be answered. The feasible ranges for decision variables provided by the IMOP solutions are also useful for decision-makers to justify the generated alternatives directly, or to potentially adjust adaptation schemes when they are not satisfied with the provided alternatives (Huang 1996b). **Figure 4** shows a flow chart of the modelling approach.

A hybrid inexact-fuzzy algorithm was proposed for solving the IMOP problem. In this approach, fuzzy MOP was used to deal with interrelationships between different objectives, and inexact optimization was used for reflecting uncertainties in system parameters, variables and their interrelationships (Huang 1996b).

5. Data Investigation and Analysis

Mackenzie Basin has an area of 1.79 million km^2, which equals the combined land areas of Great Britain, France, Germany, Spain, Portugal and Italy. With such a big river basin, data investigation, integration and analysis were critical for the success of this study. Generally, neither the analysts/decision-makers nor public interest groups had a clear set of data with respect to the problems under consideration. Four main sources were used for the identification of a variety of activities and the related objectives. The first is with decision-makers' and system analysts' knowledge and background. The second is mainly from representatives of interest groups and experts on resources use and climate change studies. Thirdly, there are a number of different interest groups in the basin, with each bearing its own objectives. One of important tasks in this impact study is to well identify these groups and examine their concerns and objectives, recognizing the rights and interests of communities in decision-making processes. The fourth source comes from literature and previous research works on the related issues. Many government agencies, institutions, information services, consulting firms, universities, and industries were contacted for data collection. Besides, results of the first- and second-order impact studies from other MBIS subprojects were also used as inputs for the integrated impact assessment. The data collection process lasts more than one year. The obtained information has first time formed a comprehensive database for all related sectors in the system, which itself can help to clarify interrelations between different activities within different temporal/spatial units.

The detailed input data for the IMOP model are provided in Huang (1995 and 1996b). They lead to several 4000 x 3000 matrices for further modelling studies. The computation was undertaken at a CAS supercomputer at the University of Regina.

6. Impact Assessment

Climate change will have impacts on the earth's ecosystems, activities, resources and human settlements. Nor-

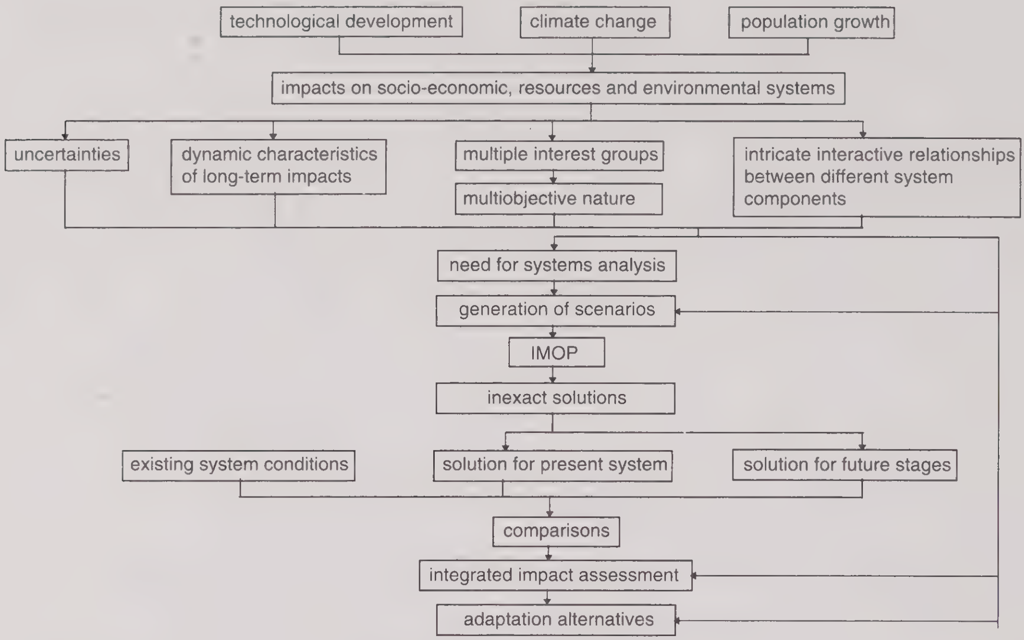


Figure 4. Flow chart of the IMOP modelling approach.

mally, the impacts are unique to each region/country and to each activity, and generating relevant resource management policies, plans, and agreements.

A warmer climate could bring new opportunities, such as longer growing seasons (for agriculture), longer shipping seasons, increased demand for tourism services, and greater productivity for northern forests. There may also be new threats, such as increased risk of forest fires, reduction in winter road service, and significant problems for buildings and other structures due to decaying permafrost. Besides, any shifts in vegetation and wildlife would have implications for park management and subsistence activities of native communities.

During the next 5 to 10 years, a number of important long term decisions are going to be made on inter-jurisdictional water resources agreements, native land claims, energy pipelines and devolution of responsibilities from federal to territorial agencies. However, many questions remain to be answered. What would be the net result of these and other climate-induced changes on the regional economy? Given the economic, social, technological and political changes now underway in the study area, what difference would climate change make? Should governments alter their current resource management plans and policies regarding water resources, resource extraction, forests, fish and other wildlife in anticipation of climate change?

One of the distinctive features of this research is the emphasis placed on design of meaningful scenarios representing different climate change perspectives, future social and economic conditions, and response options or policies. These scenarios will be translated into the model's structure to examine their socio-economic and environmental implications. In this study, scenarios of land availability variation for different activities in the basin area due to climate change were estimated and provided as inexact intervals based on the results of data investigation and analysis, as well as consideration of uncertainties. This paper only shows modelling results for four typical scenarios. Scenarios A and B are based on assumptions that land availability for agricultural/forest activities will be increased by [3.5, 6.0]% and [2.0, 3.5]% per five years, respectively, due to the changing climate. They correspond to optimistic estimations of the study system when other conditions for agriculture and forest are favorable and most of burned forest land (due to increased temperature) can be replanted. Scenarios C and D assume that most of burned forest land cannot be quickly replanted, which leads to a decreasing trend for forest cover in the planning horizon. Specifically, scenario C corresponds to a decrease of forest cover

by [6, 10]% and an increase of land for agriculture by [6, 10]% per five years (This scenario corresponds to the results from Brklacich and Brunt (1996), in which they indicated a potential increase of land availability for cereals by [31, 41]% in the study time horizon based on outputs from the existing general circulation models); scenario D is for [10, 15]% decrease of land for forest and [10, 15]% increase of land for agriculture per five years (**Table 2**).

Scenario	land available for forest (% per 5-yr)	land available for agriculture (% per 5-yr)
A	+ [3.5, 6.0]%	+ [3.5, 6.0]%
B	+ [2.0, 3.5]%	+ [2.0, 3.5]%
C	- [6, 10]%	+ [6, 10]%
D	- [10, 15]%	+ [10, 15]%

Note: "+" means increase, and "-" means decrease.

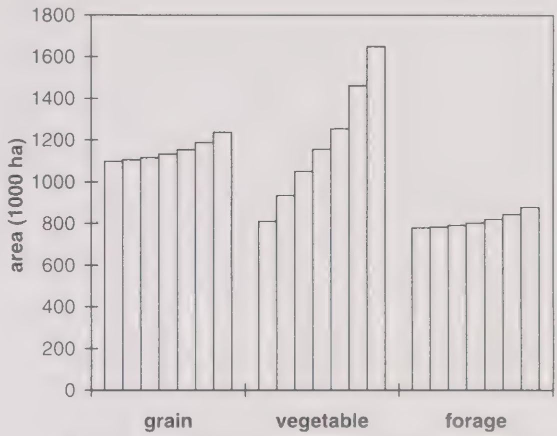
Table 2. Description of Scenarios A to D.

Generally, solutions of the IMOP will provide adaptation schemes for a variety of activities in different subareas/periods. The results indicate that a number of model outputs present as inexact intervals, which reflect the effects of input uncertainties. Significant temporal and spatial variations of land use activities would exist in the study system. They would also vary with the detailed environmental, economic and resources conditions. In the following, solutions for the four scenarios will be analyzed and interpreted in detail.

6.1. Solution for Scenario A

(1) Impacts on Agriculture

Figure 5a shows temporal variation of different agricultural activities in the entire basin. Generally, climate



Note: For each activity, column 1 at the left corresponds to period 1, and so on for the following six columns.

Figure 5a. Temporal variation of agricultural activities in the entire basin (Scenario A).

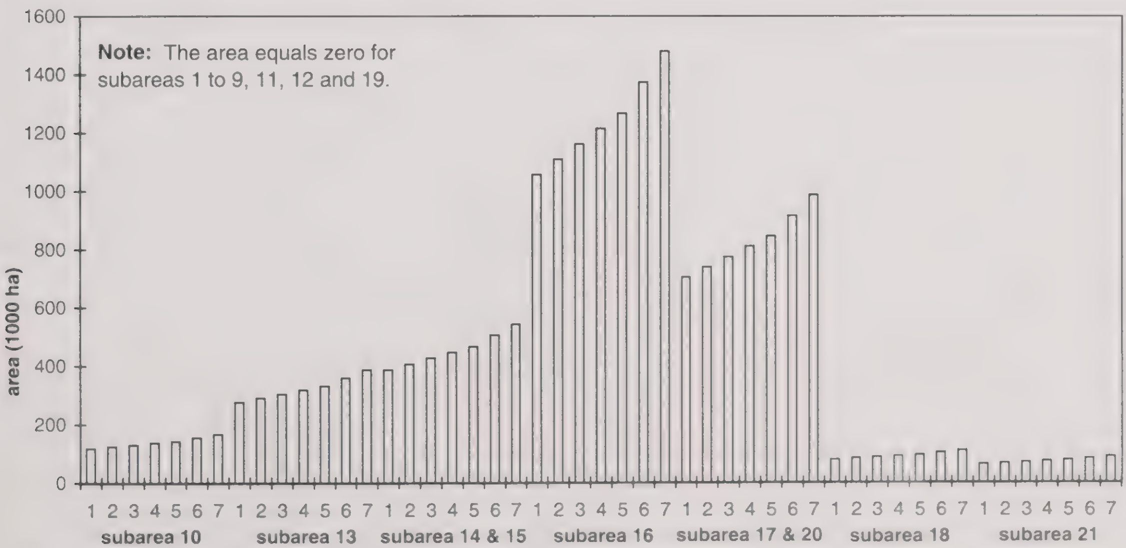


Figure 5b. Spatial variations of agricultural activities (Scenario A).

change might alter agroclimatic constraints and land suitability of soils for agricultural production. The relatively short and cool frost-free periods characterizing the current climate impose considerable constraints on regional agriculture. This climate change scenario would relax the constraints. It implies a considerable extension of frost-free period, leading to substantial increase in effective growing days (Brklacich and Curran 1994). From the IMOP solution, vegetable production would be significantly expanded following the increase of land availability for agriculture. In comparison, lands for grain and forage would only be slightly increased. This may be due to the fact that vegetable has shorter growing season and is more suitable for adapting to newly increased land availability. Also, economic return from vegetable production is higher than the others provided that good transportation service, market potential, and irrigation system are available.

Figure 5b shows variations of agricultural activities in the 21 subareas. It is indicated that the magnitude and geographical distribution of the estimated impacts are not uniform. Generally, land capability for agriculture would increase in the south, including subareas 10, 13 to 18, 20 and 21. There would certainly be a longer growing season in these subareas. By comparing agricultural land areas in different subareas, it is indicated that subareas 13 to 16 would contribute more land for agriculture, followed by subareas 17 and 20. Subareas 13 to 16 are located in Peace River Subbasin, and subareas 17 and 20 are in the south of Lake Athabasca Subbasin. Although Mackenzie River Valley also has some potential agricultural land, it is currently limited by a cool and short growing season. Under the changing climate, there would be sufficient warming to support commercial agriculture there, but moisture deficits would impose considerable restrictions (Brklacich and Tarnocai 1990). Within this scenario, an increase in irrigation demand would be expected, thereby requiring new development and/or expansion of water distribution networks.

(2) Impacts on Forest Activities

The Mackenzie Basin is an important timber producing region in Canada. About 90% of Alberta's annual allowable cut (AAC) and 20% of British Columbia's AAC come from the region. The climate-related factors for forest include: (i) growth effects related to changing growing season, moisture conditions, and possibly carbon dioxide fertilization, (ii) changing probabilities of catastrophic loss due to fire, insects and diseases, (iii) species migration, and (iv) shifts in land use (e.g. from timber production to agriculture) (Armstrong 1994).

Climate change would affect fire behaviour through changes in the drying rate of forest fuels. A preliminary study showed that the Canadian Forest Fire Weather Index (FWI) would increase as summer temperatures warm up. For example, a 3 °C increase in summer temperatures with no change in precipitation would change the FWI from a "Level 2" fire (low to moderately vigorous surface fire) to "Level 3" (highly vigorous surface fire or passive crown fire). This means that future forest fires would burn with greater intensity. Thus, there would be increased risk of fires escaping initial control efforts and becoming larger fires (Lanoville, 1990). Generally, the rates at which forests grow are projected to change with a poleward migration. However, the frequency of forest fires and their severity is expected to increase as well. This could potentially harm the region's potential for commercial forestry, especially softwoods.

Scenario A is for an increased growth in the region, with an assumption that growth increase (naturally and/or by replantation) would exceed losses due to fire, insects and diseases under the changing climate. **Figure 6a** shows temporal variation of different forest activities in the entire basin under this scenario. It is indicated that land for spruce and pine would be significantly expanded following the increase of land availability for forest. In comparison, land for aspen would have a lower expansion rate. Spruce and pine timbering may lead to higher economic return if economical transportation service and good mar-

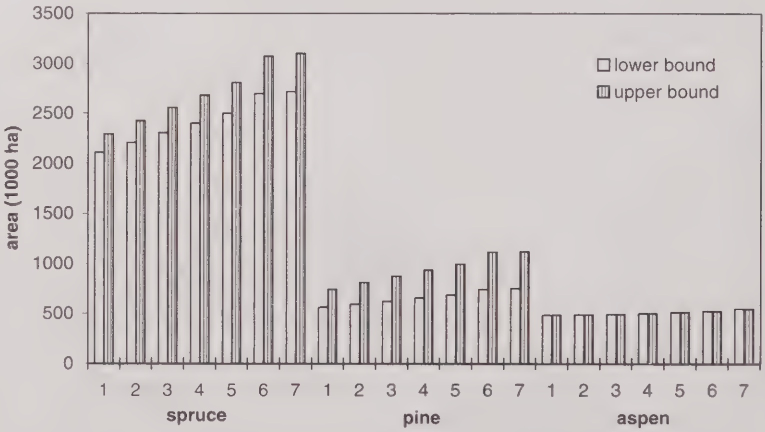


Figure 6a. Temporal variation of forest activities in the entire basin (Scenario A).

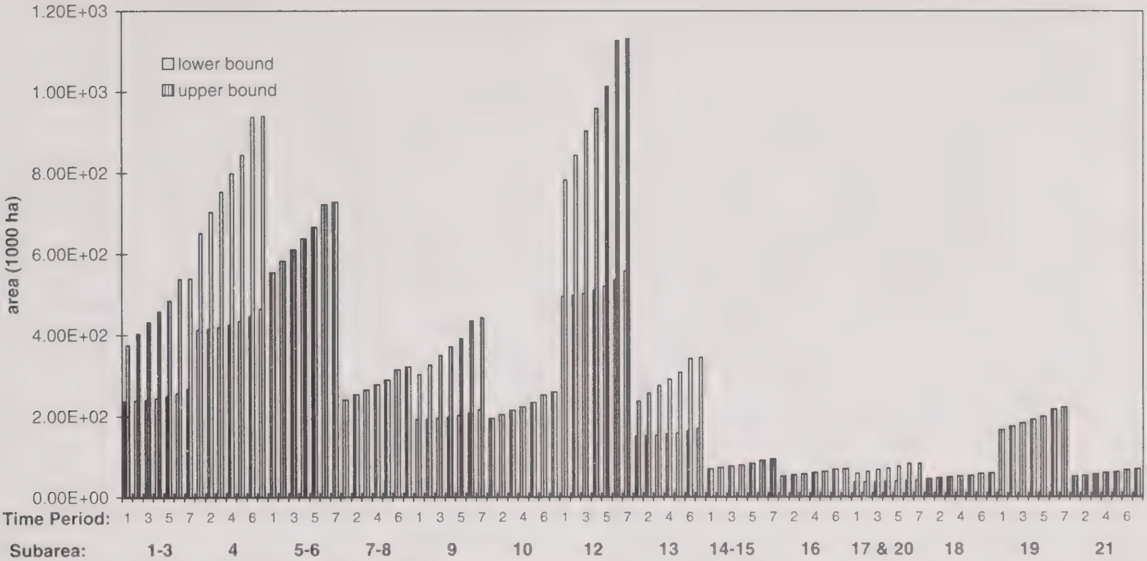


Figure 6b. Spatial variations of forest activities (Scenario A).

ket potential are available. Temporally, the expansion rates would not significantly vary during periods 1 to 6. However, the rate for period 7 would be significantly reduced. This period reaches the end of the 50-year horizon and it may be quite uncertain in terms of future climate and the relevant socio-economic and environmental conditions beyond the horizon.

Figure 6b shows variations of forest activities in the 21 subareas. Generally, forest activities would exist in all the 21 subareas. Among them, subareas 1 to 10, 12, 13, and 19 would contain more forest land. Actually, subareas 1 to 9, 12 and 19 are of no agricultural activities, and subareas 10 and 13 have low percentage of land for agriculture. Most of these subareas are located in the two north territories (subareas 1 to 8 and 12) or north parts of the three south provinces (subareas 9, 10 and 19). The only exception is subarea 13 which is a mountain area with little land suitable for agriculture.

(3) Impacts on Wetland and Wildlife Habitat Preservation

Climate Change will lead to impacts on hydrological cycle, permafrost, vegetation and wetland, which would certainly affect wildlife habitats, migration and population. Terrestrial, freshwater and marine species would experience these changes as well. **Figure 7** shows temporal variation of wetland and wildlife habitat in the entire basin under the changing climate. It is indicated that the area for them would be slightly expanded following the increase of land availability under this scenario. The expansion of wetland and forest cover may also lead to increased habitats for wildlife. However, negative impacts of climate change on wildlife may also exist. For example, sea-ice reduction due to climate change would be harmful because the base of the Arctic food web, i.e. algae that grows on the undersurface of sea-ice, would dis-

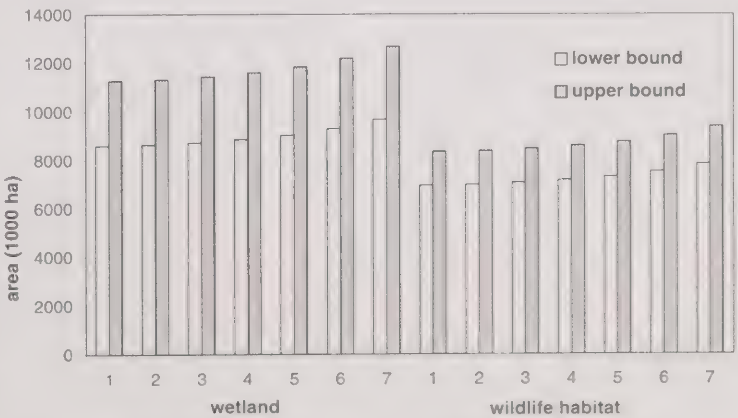


Figure 7. Temporal variation of wetland and wildlife habitat (Scenario A)

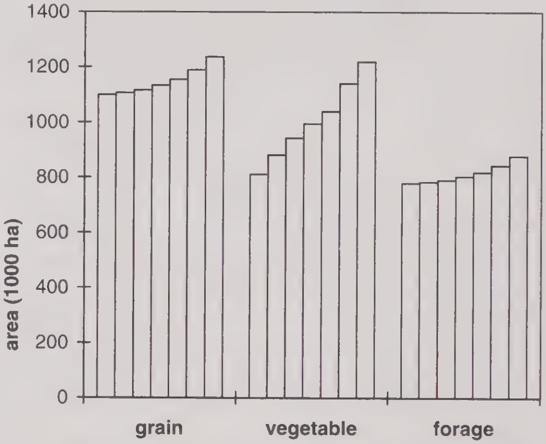
appear when the ice melts (IPCC 1990b); permafrost thaw, warmer freshwater and modified land cover would probably affect terrestrial species (caribou, bear, etc.), fish and waterfowl; increased frequency of forest fires and their severity could harm some species of wildlife.

(4) Impacts on Native Hunting

Knowledge of the natural landscape and local assets possessed by native Canadian in remote north communities is passed on to succeeding generations by an oral tradition. This knowledge has been disciplined by the empirical pressures for survival, and through concomitant conservation of the environment for future generations. Natives in the region are mostly concerned with ongoing movements of northern mammals and fish, and with the continuity of the regional forests and other resources which are needed for their traditional way of life. Thus, the constraints of native hunting concerns in the IMOP are to ensure least possible variation of areas for hunting activities. The results indicate that agricultural and other economic activities would not be significantly expanded in the north areas. Thus, native hunting in the north would be guaranteed with the increasing trends for forest, wetland and wildlife habitat under this scenario. Due to the change of land availability/suitability for different activities, some land uses may be replaced by the others in some critical regions (e.g. subareas 10, 13, and 18 where agricultural activities may be significantly expanded). However, the absolute area for hunting-related lands would be maintained or increased.

(5) Impacts on Recreation

Any changes in climate will have substantial implications for outdoor recreation and sport hunting. The probable extension of visitor season due to climate change could generate additional benefits for the study system. Despite the longer visitor season, the effects of climate change on tourism and recreational activities would be mixed rather than generally positive. Prospects of climate change may present challenging physical, biological and managerial problems for Canadian national parks, and thus potentially affect both ecological integrity and recreation use of them. For example, modified hydrological regimes due to climate change may affect riverine ecosystems which provide important ecological niches and are the foci of water-based recreational activities. The increased frequency and severity of forest fires would not only threaten secondary recreation opportunities such as hiking, nature photography and landscape viewing, but also raise questions about visitor safety. In addition, changes in vegetation types and extent after a burn will most likely affect the runoff to rivers, thereby indirectly affecting river recreation. Warmer temperature may lead to a longer navigable period and thus an extended visitor season in the fall. Warmer days in spring may cause snowmelt. The melt water percolates down through the snow and refreezes at ground level, which makes vegetation inaccessible to wildlife. Similarly, early winter rains may cause food to be covered under solid ice throughout the winter.



Note: For each activity, column 1 at the left corresponds to period 1, and so on for the following six columns.

Figure 8a. Temporal variation of agricultural activities in the entire basin (Scenario B).

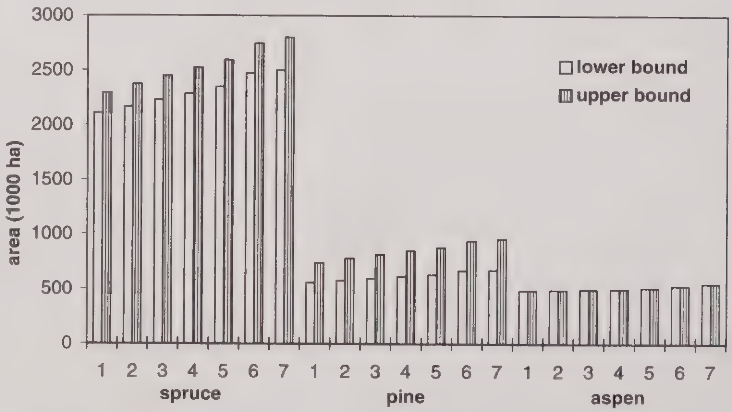


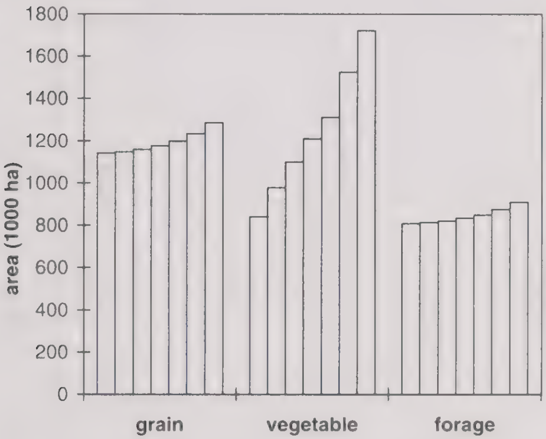
Figure 8b. Temporal variation of forest activities in the entire basin (Scenario B).

Thus, the recreation component in the IMOP is to ensure certain level of land-based outdoor recreation activities. Land for recreational purposes would not be occupied by other activities unless it is no longer suitable for desired recreational purposes due to climate change. The results indicate that, with the provision of increased land for wildlife habitats and forests and the protection of public parks, the recreational activities would be appropriately managed and potentially promoted.

(6) Other Impacts

Investigation results of soil erosion and nitrogen/phosphorus losses were input into the IMOP as constraints/objectives for the related agricultural/forest activities. The modelling results indicated that, from annual point of view, the impacts of soil, nitrogen and phosphorus losses on receiving waters would not be significant. This may be due to the fact that the percentage of land development in the basin is quite low and that there is no agricultural activities in cold winter. However, in warm and raining season, potential problems generated from growth of agricultural products in the south (e.g. subareas 14, 16, 17, 20 and 21) may exist for a short period of time.

Water uses in the basin are for purposes of domestic consumption, industrial needs, agricultural production, recreation, parks, golf courses, and tree farms. Data of water demands for different activities in different temporal/spatial units and the related water resources availability were collected, analyzed, and input into the IMOP. It is indicated that the related constraints were generally not bounded, demonstrating that water shortage problem in the basin is not significant. This is mainly due to the fact that human activities (and thus water demand) in the basin are relatively few compared with the large land area available. Spatially, the south where more human activities exist would have more water demand than the north.



Note: For each activity, column 1 at the left corresponds to period 1, and so on for the following six columns.

Figure 9a. Temporal variation of agricultural activities in the entire basin (Scenario C).

6.2. Solutions for Scenarios B, C and D

Figures 8a and **8b** show IMOP solutions for agriculture and forest based on Scenario B. Compared with scenario A, the following points arise. (i) Lower expansion of agricultural land use is allowed due to less increase of land availability ([2.0, 3.5]% for scenario B compared with [3.5, 6.0]% for scenario A). The major difference is that vegetable production would have lower expansion along with time. (ii) Lower expansion of forest land use is allowed. Especially, lands for spruce and pine will have lower expansion rates. (iii) Similar expansions for wetlands and wildlife habitats are found. This is due to the fact that one of the IMOP's objectives is to minimize deviation of wetland from the existing pattern. Thus, changes in land conditions due to climate change would mostly affect agricultural/forest activities. (iv) Lower impacts on soil, nitrogen, and phosphorus losses and water demand exist under this scenario due to reduced expansion for agricultural/forest activities.

Figures 9a and **9b** present solutions based on Scenario C. Compared with scenario A, reduction in forest land is found

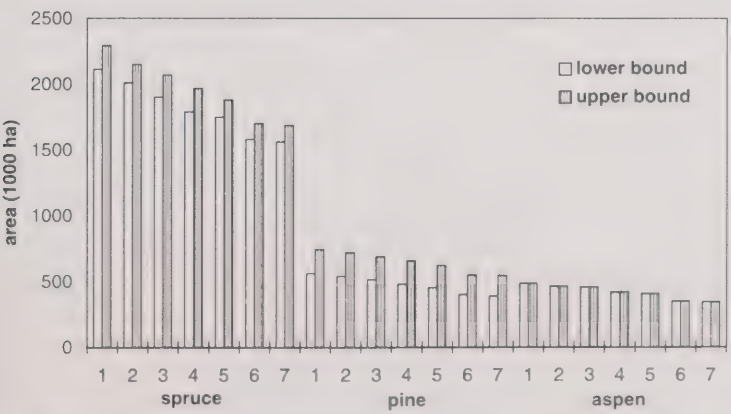
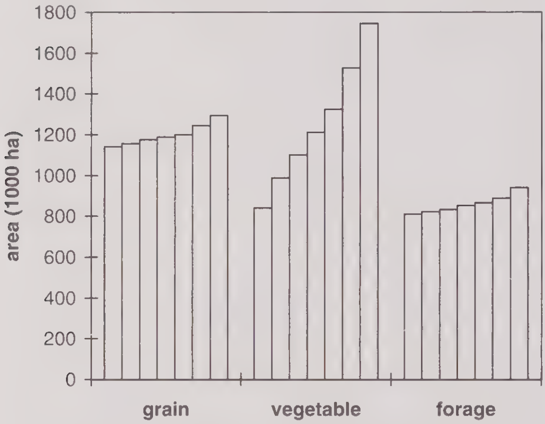


Figure 9b. Temporal variation of forest activities in the entire basin (Scenario C.)

due to increased forest fire under changing climate. At the same time, there would be more expansion of agricultural activities due to increase of land availability and potentially increased use of burned forest land, provided that conditions of water supply, transportation and market are favorable. Also, the increased forest fire and decreased forest land area would lead to significant impacts on wildlife activities. Scenario D is based on the assumption that more reduction of forest land and more increase of agricultural activities may exist under the changing climate. **Figures 10a** and **10b** show solutions based on this scenario. This solution corresponds to more extreme situations of climate change impacts.



Note: For each activity, column 1 at the left corresponds to period 1, and so on for the following six columns.

Figure 10a. Temporal variation of agricultural activities in the entire basin (Scenario D).

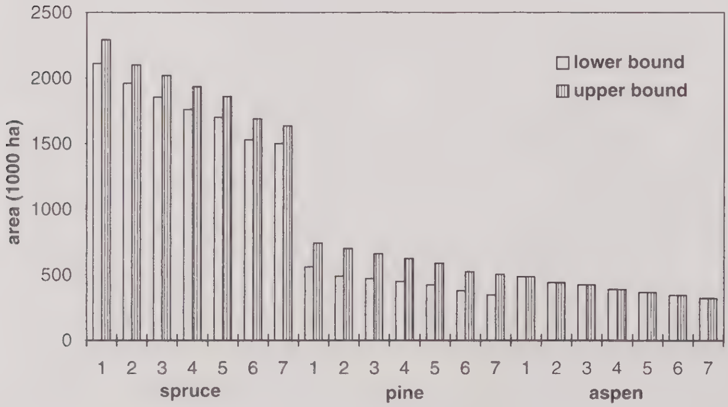


Figure 10b. Temporal variation of forest activities in the entire basin (Scenario D).

7. Discussion

(1) The integrated approach enables the inclusion of systems interaction and feedback mechanisms and can therefore yield insights that scattered information cannot offer. Since a variety of information and results from the other MBIS subprojects can be incorporated within a general modelling framework, the IMOP is also an effective means for communication between systems analysts and experts in other disciplines, as well as between scientists/engineers and policy-makers.

(2) Uncertainties in climate change scenarios were quantified through inexact intervals. This reflects the fact of data availability and quality, and the related information can be effectively incorporated within the IMOP model.

(3) When detailed adaptation strategies are to be determined, decision-makers prefer that a set of alternatives can be provided. Through the proposed IMOP, decision alternatives can be generated and interpreted for internalizing tradeoffs between different system objectives. This feature may be favored by decision-makers faced with difficult and controversial choices, because of the increased flexibility and applicability for determining the final adaptation strategies. For example, more agricultural land use may lead to higher economic benefits but more environmental/ecological consequences and more impacts on native communities. This may be suitable for more optimistic consideration under advantageous system conditions (i.e., conditions with higher "resources development allowances"). In comparison, more land for wildlife habitats and wetlands may lead to lower economic benefits but less impacts on the environment and the native communities. This may be suitable for conservative consideration under more demanding conditions. In practical implementation, the decision variable values can be adjusted continuously within their solution intervals to obtain alternatives with different environmental/socio-economic/resources tradeoffs. This will allow decision-makers to conveniently incorporate implicit knowledge within the result interpretation process, and thus obtain satisfactory and applicable strategies.

(4) The IMOP modelling results provide bases for comparisons of optimized land use patterns in different periods. Land availability for different activities will change with time due to variation of climatic and economic conditions. These temporal changes can be assessed direct-

Subarea	Grain	Vegetable	Forage	Spruce	Pine	Aspen	Wetland	Wildlife Habitat
1 to 3	0	0	0	171.7	23.576	36.977	(1397, 1793)	(1131, 1327)
4	0	0	0	298.38	27.508	78.747	(1131, 1476)	(915, 1092)
5 & 6	0	0	0	331.98	25.683	64.171	(39.0, 59.1)	(31.8, 43.7)
7 & 8	0	0	0	134.15	32.517	16.587	(553, 762)	(448. 564)
9	0	0	0	96.435	42.958	48.317	(597, 745)	(483. 552)
10	52.4	23.8	24.791	69.134	55.465	22.937	(621, 857)	(503. 635)
12	0	0	0	325.72	40.101	119.76	(917, 1292)	(742. 956)
13	81.6	34.5	118.5	69.134	55.466	22.938	(718, 926)	(581. 656)
14 & 15	169	76.1	83.639	23.303	12.698	16.482	(791, 1013)	(640. 750)
16	452	228	214.69	16.459	9.5774	13.597	(35.6, 57.3)	(28.8. 42.5)
17 & 20	284	67.1	246.38	14.913	8.4973	12.468	(262, 335)	(212. 248)
18	23.3	4.7	38.49	13.966	7.638	12.193	(417, 561)	(337. 416)
19	0	0	0	68.322	53.282	4.6052	(893, 1091)	(773. 808)
21	15.2	6	37.562	16.628	14.959	7.726	(44.6, 67.3)	(36.1. 49.9)

Table 3. Existing land use pattern in the study area.

ly. However, for impacts on land use activities, it is difficult to make direct assessment based on the existing pattern since future activities are still unknown. The IMOP approach allows this type of assessment based on the generated solutions for different activities in periods 1 to 7. These solutions provide most desirable patterns for different time stages, and thus form a common ground for effective comparison.

(5) **Table 3** shows the existing land use pattern in the study area. It is indicated that, for most of activities, the existing pattern does not have significant difference from the IMOP solution for period 1. The only exception is for vegetable production and spruce land uses, which are actually affected by many other factors in addition to climatic conditions. This result means that relatively lower impacts can be found from short-term point of view. However, as time progresses, the differences would become more and more significant.

8. Conclusions

(1) A study of integrated climate-change impact assessment and adaptation study for a number of environmental, resources and economic activities in Mackenzie Basin, Canada, was conducted through development and application of an IMOP approach. The IMOP can reflect complex system features and is useful for recognizing and assessing impact patterns. The results indicate that uncertain, multiobjective, dynamic and interactive natures of the study system have been effectively reflected. Generally, temporal variations of land characteristics and thus land use activities exist due to changes in climatic, economic and environmental conditions. However, through effective systems analysis and assessment, the impacts of climate change could be potentially adapted and the desired land use patterns for compromising objectives from different stakeholders could thus be obtained.

(2) The IMOP can reflect not only particular structure and entities of a complex system, but also processes, interactions and feedback mechanisms within the system that generate changes in its dynamics and structure. The method allows uncertainties to be effectively communicated into the optimization process and resulting solutions. It also has reasonable computational requirements and is applicable to large-scale practical problems.

(3) A potential drawback of integrated assessment models is their complexity and potentially unmanageability. Therefore, it would be beneficial for decision-makers and other model users if the IMOP can be made more transparent and have a faster turn around time through development of more effective computer software packages.

Acknowledgement

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Global Environmental Change and the Dual Economy of the North

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Introduction

The general circulation models used to project global temperature and precipitation patterns under various concentrations of CO_2 in the atmosphere estimate that the greatest changes will occur in high latitude zones in the northern hemisphere and, more specifically, in the Canadian Arctic. These findings have generated an intense concern over the magnitudes of impacts - physical, biological, economic and social - which might accompany such changes. These impacts have been discussed elsewhere, and are being extensively studied by researchers on the Mackenzie Basin Impact Study (MBIS). One aspect of this work which, to date, has received only minimal study, is the implications of climate change for Aboriginal communities. How will these communities be affected - directly and indirectly - by global warming? How have they been affected by variations in climate in the past? How vulnerable are these communities to the types of changes that are expected? Will they be more affected by changes in the economy (that is, the wage economy) or by changes in natural systems (which may affect hunting and fishing)? Addressing these questions will also allow for an assessment of how environmental change will impact communities which are, in turn, experiencing other dramatic changes.

The Inuit, First Nations and Métis people of the Northwest Territories (NWT) have already suffered from years of dislocation, and Aboriginal governments are presently in the process of healing their communities and building a more promising future for their people. At this stage of the process, Aboriginal communities need to be aware of any potential changes which may have significant effects on the environment in which they live, and which may also have impacts on their economies and social conditions. A changing climate — and the resulting impacts — warrants serious consideration by those communities.

The process of healing which most Aboriginal communities are now undertaking is, in almost every case, focused around the continuation of and respect for their histories and traditions. Within this context, two issues are crucial:

i) *the right of Aboriginal peoples to be involved in future developments in the NWT which directly affect them, according to their own traditions, language and cultures; and*

ii) *the need for adequate resources to allow them to do so.*

Aboriginal peoples are generally attempting to regain control of their lives and futures through efforts to have their inherent right to self-determination recognized. Self-determination must also be accompanied by the attainment of self-sufficiency. To be meaningful, self-sufficiency must involve more than simply increased employment in the economy imported to the North by southern companies. Instead, there is a need to recognize that in Aboriginal communities there are two, equally important sectors of the economy — the wage, or "modern" sector, and the non-wage, "subsistence" sector. Support for both of these sectors of the economy is necessary if Aboriginal communities are to develop according to their traditions, and continue to exist as distinct cultures.

The potential impacts of climate change for Aboriginal communities, then, can most usefully be examined in this context. Previous work undertaken by the principle investigator has demonstrated how changes in temperature and precipitation could affect the economy of the North, transportation systems in the Mackenzie River Basin, and energy development activities in the NWT, and has explored the dynamics of the economy of the North as well. It is important to now use this information as a base for studying how climate change will impact the lives of Aboriginal peoples in the North, both in terms of how changes in specific economic sectors (such as mining) will affect Aboriginal peoples, as well as how the impacts of climate warming may affect traditional activities and cultures.

The objective of this project was to investigate these issues by using a combination of methodological approaches. The study benefited greatly from the active participation

of the Pehdzeh-Ki First Nation (in Wrigley, NWT), and their community served as the focus of the case study presented herein. It is important to note that Aboriginal Nations in Canada are distinct, and that their cultures, traditions and goals vary. Although this paper makes reference to "Aboriginal peoples" and some generalizations are included, such generalizations are intended to refer to trends only, and it should be kept in mind that situations may be quite different between communities and governments. The specific findings of this study are unique to Wrigley, and any generalization to other Aboriginal communities must be considered in this light.

Qualitative Research Component

The first component of this research, involving the collection of qualitative information related to the dual economy, was undertaken collaboratively with the Pehdzeh Ki First Nation. Collaborative research involves the establishment of a partnership for project development, and it is based upon a perception of people as *participants of* rather than *subjects of* research. As such, the research must be flexible, and should encourage significant input from people in the partner organization or community. This type of research is fundamentally different from the standard methodology used in the physical and natural sciences, or even that used in more quantitative approaches in social science. It is important for those in the scientific community to accept the importance of collaborative research to a study of this type; without the direct involvement of the people as participants in the research, the "findings" are only "partial truths." The innovative aspect of this proposal related as much to adopting the participatory methods within the context of global change research as it did from the integration of qualitative and quantitative methods. It has only been with close collaboration from the Wrigley Dene Band that this study was possible and its findings acceptable within the context of Aboriginal peoples of the North.

The Wrigley Dene Band Council approved of and supported this project, and hired two researchers from the community to work with a researcher from the University of Victoria. Together, these three researchers developed the research focus, designed the interview and survey questions, and decided upon the format for a series of focus group meetings. They also jointly analyzed the research results and wrote the first section of the final report.

The research in Wrigley included a series of interviews examining questions related to the wage and non-wage, or formal and informal economy. These interviews were based upon a questionnaire which included both short answer and open ended questions. The open ended questions were intended to allow people to address issues that may not have been specifically included in the questionnaire, and to provide information that may not have been foreseen as important by the researchers. Introductory letters were sent to the community households, and the interviewers followed these up with telephone calls or visits to arrange a time and place for the interviews. The interviews each took approximately thirty to forty minutes, and forty-five households are represented by the interviews conducted in Wrigley. In addition, questionnaires were mailed to community members living outside of Wrigley, and eight community members who live in other parts of the country returned these surveys.

The interviews were then followed by three focus group meetings, meant to clarify and explore in greater detail some of the issues raised during the interview process. The focus groups meetings, one with community elders, one with hunters and trappers, and one with youth, were each attended by between eight and ten people. Five general questions were developed to stimulate discussion at the meetings, but the participants were encouraged to move beyond the questions and raise any issues they felt important. The focus group meetings each lasted approximately one hour.

Quantitative Research Component

In order to assess the socio-economic implications of climate change on Canada's North, and in particular, on the dual economy of Aboriginal communities, it was necessary to postulate some likely scenarios which may arise as a result of a warmer climate. It is believed that the most common ways in which climate is likely to effect the economy is through changes in the transportation and non-renewable and renewable resource sectors. This component of the study concentrated on the effect climate change may have on the renewable and non-renewable resource sectors. It originally intended to examine three distinct scenarios - an impact on the forestry sector and two large scale oil development projects in the Northwest Territories. However, an attempt to model the impact of increased activity in the *Forestry and Logging* sector could not be completed due to limitations in the input-output data for this sector.[1] Thus, the study concentrated on computing Aboriginal and non-Aboriginal employment impacts associated with two large oil development projects. The impacts were divided this way in order to integrate them with the qualitative data gathered in Component I of the project.

The effects of climate change were assessed by computing employment impacts for two large oil developments in the NWT at the 12 sector level. The impacts were calculated using a dynamic multiregional input-output (MRIO) approach developed by DiFrancesco (1994). The employment increases were calculated for both Aboriginal and non-Aboriginal people using data obtained from the Labour Force Survey (GNWT)[2]. After the total impacts were computed, they were disaggregated to the Deh Cho Region level in order to better integrate the results with the data collected for the community of Wrigley as reported in Component I of the study. To accomplish this, simple ratios were applied to the total figures. For example, the ratio of the Aboriginal labour force in Deh Cho divided by the total Aboriginal labour force in the NWT was used to determine the Aboriginal employment impacts. It was felt that disaggregating impacts in this manner presented a conservative estimate since most of the jobs would likely be created in the Mackenzie Valley and thus have, at a minimum, a proportional impact on the Deh Cho region. To disaggregate to the level of Wrigley would be unrealistic. Furthermore, some of the required data was deemed confidential by the Bureau of Statistics (GNWT) due to the small size of the community (sample was 107 out of 146 residents).

Combining the Qualitative and Quantitative Data

Finally, an attempt was made to combine the information collected in the first component with the data resulting from the second. The employment impacts by sector which were produced using the computer modelling techniques described above were analyzed in the context of the qualitative information provided by the people of Wrigley. The predicted changes in employment were considered in terms of several issues identified as important, including the location of the jobs, the types of employment to be created, the required training, and whether or not the jobs are temporary, seasonal or permanent. Further, the implications of changes in employment in terms of the community, its membership and their culture were considered. The results of this analysis are presented in the final section of this paper.

"Two Economies" in the North [3]

The existence of technologically advanced extractive, processing, and service and administrative activities along with a traditional hunting, fishing and trapping economy has resulted in a frequent reference to two ways of life in northern Canada today, commonly referred to as the two economies, or the dual economy[4]. The components of this dual economy are sometimes referred to as the "formal" and "informal" sectors. As Ross and Usher (1986) note, there is a:

> wide range of activity in our society that is not carried out by large corporations or governments and, indeed, is hardly recognized by them to exist. Such activities include the domestic economy of the household and the local economy of the community. Taken together, most of the local activities carried out in these areas may be thought of as composing the "informal economy," in contrast to the formal, commercial and public sector economy (p. 2).

According to the authors, this informal economy is characterized by a number of factors. It is typically found in small, isolated or rural communities, it is based largely on self-employment, rather than wage employment, and it is usually organized along family or kinship lines. Goods and services are often exchanged without money transactions, and when money is involved it is usually used to facilitate exchange rather than to increase profits. Therefore, the drive to accumulate capital for its own sake is not generally pervasive. Productio n is also usually decentralized, and is under household or community control. Production is often owner-operated, and is unquantified, unrecorded, uncounted and often invisible. Instead of doing specialized jobs making parts and components of incomplete things for unknown destinations, "whole" jobs are undertaken for people known and depended upon. The effects of work and produce tend to be felt locally, and there is an understanding and involvement in and control over what is going on. Owners, managers and workers are very often the same people, and rather than a focus solely on output, how things are done, who receives the output, and how people relate to one another are as important as what is produced.

The rise of large-scale resource development activity and of large, modern government centres made it seem that the two economies functioned independently. There seemed to be no linkages between them, which gave rise to the notion of a dual economy. It was correctly observed that economic growth in the industrial sector generally failed to result in growth in the Native sector. It was incorrectly concluded, however, that the two sectors were therefore functionally independent, and that the industrial economy was where development took place, while the informal economy was stagnant and incapable of improvement (Ross and Usher, 1986). Policies based on this analysis involved moving people out of the traditional sector into the modern one. But

the economies are related, and no one operates solely in one economy. As Ross and Usher (1986) note:

> ...both environments are essential in our society, and the problem is how to maintain each without disrupting or undermining the other. There is no doubt that the growth of industry and commerce has so far been at the expense of the informal economy, and that whether through necessity or choice, most Canadian households and other informal economic units have come to rely more heavily on the formal economy. Should we assume that it is either inevitable or desirable that this shift from informal to formal continue indefinitely? ... In recent years, there has been an unprecedented level of concern with the impact of development — both social and environmental. ... Wherever people have risen up in defense of their community, the struggle has been about more than a piece of land or property or levels of income. It is also a defense of a way of life that can only be sustained by a community of people — a way of life that is not just a combination of interchangeable factors of production (p. 46).

What many Aboriginal peoples believe they need now is a humane balance, so that they can build a lasting homeland in which local communities can continue wildlife harvesting for cultural subsistence, while they can also draw upon the wage economy to gain a share of the prosperity which other northern residents take for granted. Indeed, there now exists in Canada's North a precarious balance between modern and traditional ways of life, between the North as an economic frontier and a native homeland (Sadler, 1990).

For most Aboriginal peoples today it would be difficult to imagine a life without money, stores, machines, radios, doctors, and mosquito sprays. Many Aboriginal people desire a number of the benefits from the industrial economy, and to acquire these benefits they must become involved at least partially in the wage economy. In Stabler's study, for example, he found that 36 percent of NWT males who are engaged in traditional pursuits also hold jobs in the modern sector, and that of the 64 percent not employed, those who want a job outnumber those who do not by a factor of eight to one. Very few people remain dependent on the traditional domestic and exchange sectors alone; most rely on a mixture of traditional activities and wages. According to Ross and Usher (1986), a typical household has several streams of income: wage employment, trapping and handicrafts, hunting and fishing, and transfer payments. Many of these sources are seasonal, members may occupy any number of them, and their incomes are often pooled.

It has been suggested that subsidies or wage employment have become important to the maintenance of traditional activities, which now require a transfer of funds from the cash sector to meet equipment and transportation costs. Traditional activities require large amounts of cash for the purchase of modern equipment, and because of declines in prices for furs and seal skins, harvesting does not always provide an adequate income for the purchase of this equipment. In their study of an Inuit community, for example, Quigley and McBride (1987) found that people do not use social assistance as a form of basic support, since the families were involved in the traditional sector to a large extent; rather, welfare in this context can be viewed as providing the cash needed by families whose primary source of income is country food.[5] People may also take on seasonal or full time work to support their traditional activities. In this study, people did not indicate that their employment in the wage sector significantly effected their hunting, trapping and fishing activities in terms of the money available to purchase equipment. However, in several instances this was explained to be a result of the fact that they had already purchased the equipment necessary, or because they were able to borrow and share with their family and neighbours.

It has also been suggested that in other ways, the informal economic sector is adversely affected by the formal economy and some people claim that the development which has taken place in the past, uncontrolled by Aboriginal peoples of the North, has to some extent undermined their traditional lifestyle. For example, the issue of time allocation has been seen to be important; wage income is often obtained at the expense of traditional activities, so that the net benefits of wage employment are not as high as might be expected. In a study of the fishing activities of the people in eleven communities in and near the Mackenzie River Valley in 1990 (Northern Affairs Program, 1990), the majority of people claimed to be fishing about the same amount as they were eight years ago, but one-third of the people surveyed said that they were fishing less. The primary reason they cited for this change was that wage employment meant that they had less time to be on the land. According to Ross and Usher (1986), because of the time factor, those who want to continue in the non-wage sector may find welfare payments a more reasonable source of income than wage labour, and social welfare benefits have assumed great importance in past years. In this study, the interview participants suggested that involvement in the wage sector has not reduced the time they have available for traditional activities, as many of them sug-

gested that they are satisfied with being able to go out on the land on weekends.

However, it was clearly demonstrated in this study that the people of Wrigley clearly want the traditional Dene cultural values and practices to continue, but they also see potential benefits from wage employment for their children. Several people indicated that they want their children to be able to participate in both aspects of life, that "they should be able to work for wages but still be able to go out on the land to hunt, trap and fish," and that "they should be able to do both — paid jobs and being able to live off the land."

Generally, Aboriginal people want a choice so that those who want to can find a job in the wage economy, and those who prefer can consider some combination of wage employment and subsistence pursuits. This view is illustrated by the resolutions of the Inuit Circumpolar Conference (ICC) regarding the environment and renewable resources which, according to past ICC President Mary Simon (1992), promote "an integrated approach to assure that there is a balanced relationship between the critical need for development and our desire to maintain sustainable lifestyles based on our renewable resources" (p. 21). The importance of both economies is also vividly expressed in the Constitution of Nunavik (the Inuit nation in northern Quebec), which includes in its Charter of Rights and Freedoms: "the right to develop a balanced and diversified northern economy which accommodates and promotes both wage and subsistence economies."

Further, each of the Land Claims Agreements signed to date with Aboriginal Nations in Canada's North have contained extensive sections outlining the need for economic development measures, including, among others, provisions regarding training, proactive recruitment of Aboriginal peoples for employment, a review of existing job qualifications to remove inappropriate requirements and cultural biases, support for Aboriginal entrepreneurs, and assistance to emerging Aboriginal firms and assistance for them in accessing contracts. At the same time, these agreements also contain extensive provisions regarding support for hunters, trappers, fishers and those involved in the production of arts and crafts. These provisions include income security programs, training, providing capital and other support mechanisms, as well as guarantees that land will continue to be available for people undertaking traditional activities, and provisions regarding fish and wildlife protection and joint management and quota establishment processes. The Gwich'in Comprehensive Land Claim Agreement and the Sahtu Dene and Métis Agreement, for example, state that:

> Economic development programs in the settlement area shall take into account the following objectives: that the traditional Gwich'in (Sahtu Dene and Métis) economy should be maintained and strengthened, and that the Gwich'in (Sahtu Dene and Métis) should be economically self-sufficient.

In this study, many of the interview and survey respondents echoed this perspective, saying "it really depends on their individual lives. Should they choose to have paid jobs, that's fine. But should they choose to live traditionally, that is also fine, as long as they are doing something that is important to them," and "it is important for my children to be part of the wage economy so they can be independent. It is equally important for them to know how to live off the land. Our children must be taught to learn to live in both worlds. They must be proud to be Dene living in the modern world. They have to take the best of both worlds and create a better world themselves. We live in both worlds and are respectful of the good in both."

However, economic development of simple and abundant traditional resources often gets little attention in comparison to industrial development,[6] and there is the potential for more and more people to increasingly accept values and assumptions about progress which are imported from the southern society. According to Portes and Sassen-Koob (1987), theories of industrial development usually include three assumptions: i) that informal activities are essentially transitory, being a consequence of the imperfect penetration of capitalism into less developed regions and destined to disappear with the advancement of industry-led growth; ii) that the principle reason for the continuing existence of an informal sector is to keep a redundant labour force alive; and iii) that the informal sector is a manifestation of underdevelopment. The authors argue, however, that available information contradicts these assumptions, and that the informal sector has proved to be resilient and in fact increasing in size and scope. As Quigley and McBride note, in the case of the NWT there is a widespread but mistaken view that economic development must include the introduction of business and wage labour economy, and this view is based on the perception that the traditional sector will inevitably decline and that the crisis believed to be in existence in many remote northern communities is due to the difficulties in stimulating business enterprises in these communities. As the authors note, "this view has recently attracted considerable criticism, not just because of the colonial mentality underlying it, but also because scientific research has largely

refuted both the assumption that the traditional sector of Inuit communities is in decline and the suggestion that this sector cannot form an important basis for future economic development plans" (p. 204).

It is important that business development and employment opportunities be expanded, and there is a need for more and better designed education, training and business support programs. But the traditional economic sector is key in many communities, and unless policies supporting subsistence traditions are implemented, there will be continuing pressure to accept development for short term gain. According to Ross and Usher (1986, p. 146), the "advance of industrial development in the North has resulted in widespread conflict over land use, resource management and the allocation of public and private funds, as well as the concerted encouragement of Native people to join the industrial labour force. In short, direct competition has arisen between the two economies for the essential factors of production: land, labour and capital."

As the authors further note, the terms "employment" and "work" in industrialized societies have become over time almost synonymous in their usage, and many of the people in the North who hunt, fish, cut wood, and repair their own engines would be classified in a typical government employment survey as unemployed, even though they work very hard and produce things of essential value. Not to be paid is to be thought of as not productive and not working and, consequently, as having no economic value and no legitimate claim to income. As a result, there are few instances in which employment policies encourage and assist in developing individual and community based enterprises. Emphasis is on "find a job," and people have long been encouraged to think of development in terms of mega-projects employing thousands of people. There is a need for official recognition of the fact that harvesters are "employed," that harvesting is an occupation, and that the people involved in that activity require appropriate support programs. As the Standing Committee on Aboriginal Affairs notes in its report (1993):

> To Aboriginal people, trapping is more than an occupation. It stands for a cultural tradition, a way of life, and an economic freedom that, once lost, is irretrievable. As Canadians, we should do everything within our power to retain the Aboriginal people's traditional lifestyle whose existence makes this country unique in the developed world.

There are a variety of programs available to assist people engaged in hunting and trapping in the NWT, but Quigley and McBride claim that these programs are quite restrictive in terms of eligibility and usually assume that applicants will contribute a substantial portion of the funds required for this activity from their own cash resources. Alternative sources of money for hunters are often poorly funded, relatively difficult for people to tap, and insufficient for dealing with problems. Many hunters' and trappers' associations exist and are among the most important organizations in the North. At present, however, they function largely for the exchange of information, as well as for some activity to encourage the marketing of furs, food, and hunting and fishing based tourism opportunities. The power of these associations remains quite limited, and many presenters at the hearings held by the Royal Commission on Aboriginal Peoples argued for increased support for traditional ways of life and for their extension as the basis of local and regional economies for Aboriginal people living in the more remote parts of Canada. These arguments for support are made on the grounds of both sound economic practice and cultural affirmation (RCAP, 1993). Again, the Land Claims agreements signed to date recognize this priority, and include commitments to measures to support hunters, trappers and fishers. The Standing Committee on Aboriginal Affairs (1993) also recommends that Aboriginal trappers be encouraged to become more involved in value-added aspects of the fur trade and that their talents be extended into more diverse activities such as design and clothing production.

Aboriginal peoples do not want to remain in the past, and there must be a recognition that their societies will change and their cultures will evolve. However, the direction of any changes must be determined and guided by Aboriginal peoples themselves. The North needs development, but development which is culturally appropriate, self-directed, sustainable, and equitable. Aboriginal peoples will oppose development if it is defined in other people's terms; as Kassi (1990, p. 90) notes "we are fearful of imposed pressures on our lifestyle — about the so-called development that promises — but never delivers real benefits to the people of the North ... it is time for our kind of development: which recognizes that the world's resources are linked and that they are essential for human survival and should be protected." This sentiment was reflected by the people of Wrigley, as well. In the study of tourism development potential conducted in 1990 (RT and Associates), members of the community clearly indicated their support for related programs ***only if*** the community retains control over the pace and types of developments to ensure that the benefits accrue to the people of Wrigley. They also expressed a strong preference for community

ownership of tourism businesses. Many people mentioned their concern that without direction by members of the community, parks development and other initiatives might be disruptive to the traditional nature of the community, and it was clearly indicated that any development must be compatible with existing traditional lifestyles. In other words:

> Our [Aboriginal] people no longer want to be in a situation where you can have a mine right outside your door but the resources from that mine go to somebody else, and the decision as to when that mine is going to be developed is made somewhere else. This kind of development leads to social disruption. The mobile out-of-town workforce, continuing high unemployment, racism, pollution, and the disturbance of hunting, fishing and trapping grounds all take their toll when we don't have the power to make decisions affecting our people (Erasmus and Sanders, 1992, p. 11).

Summary and Conclusions

According to the estimated employment impacts for the scenarios used in this study, employment will increase throughout the NWT in the eight to ten year period following the commencement of the oil and gas development projects. In order to understand the significance of this change for any *individual* community in the NWT, it must be considered within a context which includes the perspectives of members of the community. By integrating the information obtained in the qualitative research component of the study with the quantitative modelling, we can get some sense of the impacts of climate change on communities such as Wrigley.

Generally, the people in Wrigley indicated a strong desire for increased employment and new jobs. Youth, parents and elders in the community all want young people to have access to paid work and the so-called modern economy. The people of Wrigley indicated that they do not want future generations to be excluded from developments which may take place, and they want people from Wrigley to have access to what they recognize as the benefits of wage employment. The emphasis placed by so many of the community members on training for young people is indicative of this perspective.

The issue of training is perceived to be critical if people from communities like Wrigley are to take advantage of any employment opportunities which do arise. Those who participated in this study made it very clear that training and education have considerable meaning to the people of Wrigley. As the first component of this study indicates, basic levels of education are necessary if training for even unskilled jobs in the resource development field is to be successful. However, as indicated above, the people of Wrigley do not desire only unskilled jobs. Rather, the participants in this study generally indicated a desire for skilled, managerial and professional jobs. It is relevant, then, that the employment impacts generated by the model in Component Two of this study indicated that the majority of jobs created by both scenarios would be in the *Community Business And Personal Services* sector of the economy. This result would most likely be seen as positive from the perspective of Wrigley community members.

However, it is possible that any employment resulting from the scenarios described above - the most plausible in terms of the economic impacts of climate change - would not, necessarily be stable employment. As the literature cited in Component One of this study indicates, developments in the oil and gas industry in the past have usually resulted in short term "boom and bust cycles," and any resulting employment has not tended to last for a substantial period of time. The results of Component Two are consistent with such prediction. In all sectors of the economy, the employment increases would peak in the fourth and fifth years following the project initiation, and would decline rapidly until the impacts are negligible. Past experience has demonstrated that this type of employment trend has had little long term benefit for the people of the NWT.

There is also some question related to the location of the new jobs. As discussed above, the SCONE Report (1989) indicated the inappropriateness of employment related to the non-renewable resource sector because of the tendency for such jobs to be located in remote areas. In terms of this study, it was suggested that if jobs created are located far from Wrigley, the implications for the community are not clear. The responses to the interviews indicate that people *will* move if necessary in order to obtain work, and employment is generally a priority. However, a movement of community members to other parts of the NWT could have significant impacts — both personally and collectively — on the community. In general, most people do not want to leave Wrigley in order to obtain employment, and if they were to relocate it would have a disruptive effect on their lives. Ties to family and friends in the community are very important to most of the people who responded to the questionnaires, and the separation of people from the community would likely be perceived as negative. This situation may be most pronounced for young people, who may be the most mobile and likely to move, or the most educated, who also

would be more likely to leave the community. A connection of young people to their families, elders and traditions is very important to the people of Wrigley, and may be a strong enough force to keep residents in the community rather than endure dislocation.

In this regard, the interaction of wage and non-wage activities is important. The people who participated in the interviews and focus group meetings which were conducted in Wrigley were very clear about the importance of traditional activities such as hunting, fishing and trapping. The continued practice of such activities is seen as a crucial aspect of the continuation of their traditions and cultures, and were said to be an important element of passing on the values and culture to the young people of the community. The study demonstrated that people may continue to hunt and fish in other locations if they relocate, but this situation will eliminate the sharing of equipment and harvest which is currently the practice. This disruption may have a detrimental effect on some people of the community. In particular, many elders no longer able to hunt and fish rely on country food provided by others. In addition, the study participants indicated the importance of the association between young people and the elders and the teaching of Dene ways from generation to generation. It is possible that such a connection could be disrupted by the relocation of many community members.

It should be noted, however, that the MRIO indicated that the scenarios used in this study *would* result in employment within the Deh Cho region, and a move within the region is not seen to be as disruptive as a move further away. As a result, it is difficult to determine the spatial outcomes associated with climate change impacts, particularly for small, remote communities such as Wrigley. The concept of "community" is very strong in many Aboriginal communities in the North, and it appears that any economic benefits associated with changes in climate in the North, unless they occurred within the Deh Cho region, would likely have a minimal impact on Wrigley.

It is also difficult to ignore the rapidly changing political climate in the North. The dynamic nature of existing institutions and land ownership can not be ignored in a study of long-term impacts. Settlement of land claims may mean that future developments will be co-managed by Aboriginal nations. This situation may have tremendous implications for any non-renewable resource projects. It is likely that if development takes place in an area included in a claims settlement, Aboriginal peoples will be involved to a significant extent in the determination of the impacts of the project. Projects developed in these regions may also be subject to special terms, with provisions regarding benefits to Aboriginal nations attached. Finally, some of the resource royalties resulting from the development may go directly to Aboriginal communities. As a result, it is extremely difficult to assess the impacts of any scenario taking into consideration the changing political situation. This project did not attempt to consider this variable, although it is most likely that substantial changes will take place.

The primary objective of this of this project was to investigate the potential impacts of climate warming in Canada's North by integrating qualitative and quantitative approaches to research. It is clear that such "integration" of methods and methodologies is a useful and necessary avenue for applied research; it allows for both objective and subjective insights into the dynamics of society and culture, and is particularly effective when dealing with various spatial levels of data and information. One cannot simply apply the general projections of GCMs to local communities without a thorough understanding of those communities and perspectives from the people living in those communities. This project was also unique in bringing a participatory perspective to the study of global change impacts; further work on adaptation strategies must include such a perspective. Although the "results" — at least in a traditional scientific sense — were indeterminate (largely because of the dynamic political situation), the study achieved its intention of demonstrating the utility of integrating qualitative and quantitative approaches to applied research, and sets the stage for future participatory research on the impacts of global environmental change.

Notes

1. Due to confidentiality, Statistics Canada ascribed data for this sector to "other manufacturing" for the base year.
2. Personal communication with Dave Stewart, Bureau of Statistics, GNWT.
3. DIAND (1991) actually refers to "three economies" in the North - the wage sector, the traditional or subsistence economy, and the social assistance economy. However, in the context of self-determination and self-sufficiency it is clear that the third sector is neither desirable nor viable, and every effort must be made to eliminate the existing dependency on government assistance payments.
4. As Usher (1980) notes, these so-called "two economies" — really referring to two ways of life (the

traditional and the modern) — are more correctly understood as two modes of production (including not only economic factors of production: land, labour and capital), but also social organizations and supporting ideologies and values. Usher also continues to refer to the concept of "two economies," however, for consistency with the literature.

5. The authors also note that there are two problems associated with this situation. First, many government policy makers do not recognize this effect of social assistance payments and, as a result, fail to understand that cutbacks will, in the absence of alternative hunting subsidies, result in reduced participation in this key aspect of the community economy. Also, welfare payments remain too small to assist young people to acquire the necessary start-up capital for the purchase of equipment.

6. For example, the activities of people engaged in traditional pursuits are usually not included in analyses of labour forces because they are not seen to be participating in the economy (DIAND, 1991).

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9

EXTERNAL REVIEW OF THE STUDY PROCESS

MBIS and Sustainable Development: An Outside Perspective

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Introduction

In this assessment of the Mackenzie Basin Impact Study (MBIS), two observers from the United States explain why MBIS can serve as a useful and influential model for the design of future sustainable development projects. While MBIS was not a sustainable development program per se, but rather a study of the potential impact of global warming on a particularly susceptible geographic region, the MBIS project is important in the context of sustainable development because it set a precedent. It was one of the first major planning efforts anywhere in the world to seek the active participation and input of stakeholders in a scientific and technical study.

Originally, MBIS was designed as a conventional integrated assessment based on the interdisciplinary participation of government scientists. Because of the concerns of the aboriginal peoples whose futures were at stake, however, the process evolved into a scientist-stakeholder collaboration. At first the scientists were wary of this collaboration, fearing that scientific integrity would be impinged upon by local demands. But as the study progressed, the scientists began to appreciate the input of the aboriginal[1] residents of the Mackenzie Basin, especially with regard to their intimate and detailed knowledge of the environment.[2]

The Road to Sustainable Development: A Handbook for Citizens

In a Policy Research Project conducted by students of the Lyndon B. Johnson School of Public Affairs for the U.S. Department of Commerce, MBIS was chosen as one of eight sustainable development programs that could serve as models for future cooperative initiatives by government agencies and non-governmental organizations (NGOs). The goal of the Policy Research Project was to publish a practical guide which would assist individuals and non-governmental organizations in establishing successful new initiatives for sustainable policies and programs. The product was *The Road to Sustainable Development: A Handbook for Citizens,* submitted to the Department of Commerce for publication in 1996.

In all eight of the programs examined in the handbook, the key element essential to achieving success — widespread economic benefit that could be sustained over the long term — is clearly identified to be *active and continuous participation by all of the stakeholders involved:* government, the private sector, and the individuals whose lives would be affected most directly, for better or worse, by the development project under consideration. The absence of this third component — individual citizens and groups representing local interests — has perpetuated development projects which have faltered from the cumulative weight of adverse impacts on local people and the resources on which they depend for their livelihood.

At the same time, the handbook acknowledges that effective citizen participation — early and continuing involvement that can actually affect the decisions and outcomes of a development project — is difficult to accomplish for many reasons: political, financial, administrative, logistic, and cultural. By examining programs such as MBIS which have overcome these obstacles and achieved genuine participation by local stakeholders, the handbook identifies the elements common to their success and presents a model with guidelines for structuring sustainable development initiatives, in particular those organized by NGOs.

The concept of optimizing the sustainability of development projects by actively involving local stakeholders in their planning and execution is not new. In its most completely developed and systematic form, this idea was originated in 1977 by a Canadian, Professor C. S. Holling, working with the United Nations Environment Programme's Workshop on Adaptive Assessment of Ecological Policies, and became more widely known with the publication in 1978 of Holling's *Adaptive Environmental Assessment and Management.*[3]

Now, in *The Road to Sustainable Development,* many of the elements first articulated by Holling have been extended to the arena of community and regional planning, focusing specifically on ways to increase the effectiveness of NGOs in achieving sustainable development:

- establishing a dependable information base that is continually upgraded with new information;
- involving all stakeholders, or their representatives, in

the planning process from its inception;

- utilizing a workshop format that allows stakeholders with different interests to communicate effectively with one another, form strategic alliances, and reach compromises;
- asking "what if?" questions and developing alternative hypothetical scenarios;
- introducing a time-line to the assessment of probable beneficial and adverse impacts, so that the unfolding of reversible and irreversible changes can be projected through future time;
- the continuing participation of stakeholders beyond the planning phase, into the construction and post-construction years; and
- the ability of stakeholders to use feedback from actual outcomes of the development to adjust its scope and pace on a contingency basis.

The Case Studies

In selecting the case studies to be analyzed, the student participants in the Policy Research Project asked themselves four questions:[4]

1. Did the project aim to achieve or contribute to the cause of sustainable development?
2. Did it involve grassroots non-governmental organizations?
3. Did the project actively seek citizen input?
4. Was the case rich in lessons?

They also looked for cultural and geographic diversity in the case studies, and for a wide range in the focus and impact of the projects, because it was seen as important from the outset to ensure that the application of the resulting model could be generalized to any sustainable development effort.

The eight case studies selected occupy four main categories: (1) community development; (2) regional development; (3) technology-based sustainable development; and (4) empowering stakeholders. The handbook notes, however, that regardless of the type of project, geographic location, or cultural heritage, successful sustainable development programs throughout the world "share common themes, employ common strategies and suffer common barriers."[5]

The following summaries of the seven case studies conducted along with MBIS are based on fuller descriptions in The Road to Sustainable Development. From these descriptions, it is clear that MBIS and the other seven projects set an important precedent for sustainable development programs: the inclusion of local stakeholders.

Community Development

The three community development case studies focus most directly on the empowerment of individual stakeholders at the local level, through grassroots initiatives facilitated by NGOs.

1. Sustainable Cities: Chattanooga and Portland (U.S.)

Chattanooga, Tennessee, and Portland, Oregon followed different paths to sustainable solutions. Chattanooga, through the efforts of a non-profit organization working closely with involved citizens, corrected years of physical, cultural, and social decay. Portland, on the other hand, already enjoyed a high quality of life and outstanding natural beauty. Portland's citizens, working with government agencies, were able to protect these attributes by proactively anticipating and neutralizing the potentially harmful impacts of impending growth and urban sprawl.

2. Social and Sanitary Action Committee (Ivory Coast)

In the sub-Saharan West African nation of Ivory Coast, a Peace Corps volunteer recorded a detailed account of her experiences and observations in helping to establish a Social and Sanitary Action Committee (CASS) in Biankouma, an agricultural community of about 15,000. CASSes were the result of a cooperative program between the Ivorian government and U.S. Agency for International Development (USAID) to build participatory structures that would facilitate community development. In some cases, as at Biankouma, Peace Corps volunteers served as project initiators and facilitators. The greatest challenge faced by volunteers and community members in establishing CASSes was the lack of any pre-existing framework for citizen participation. Because all previous development activity had been carried out by government agencies, the residents of Biankouma lacked the confidence and experience necessary to undertake community action initiatives. The main objectives of the Peace Corps volunteers, therefore, were (1) to create broad stakeholder participation, (2) to instill confidence in local citizens so that they could work as partners with government agencies that would otherwise have viewed them as rivals, and (3) to institutionalize the CASSes so that they would be self-sustaining and not rely exclusively on continuing outside impetus and support.

3. First Nations Development Institute (U.S.)

The First Nations Development Institute (FNDI) was

established in 1980 as an NGO committed to community development and prosperity for Native Americans. FNDI provides technical and financial assistance to tribes with the goal of engendering self-confidence and economic self-reliance. An important finding of this case study was that community development plans conceived "off-reservation" have seldom been successful. Instead, effective policy results when the process grows from the stakeholders' cultural framework and is grounded in local realities. FNDI follows the strategy of identifying common philosophical values to generate support from a broad, inter-tribal constituency. Its wide-ranging activities include advocating tribal rights at the federal level, generating funds for enterprise startups, and initiating self-sustaining community development projects. FNDI's experience has shown that to be viewed as successful by Native Americans, sustainable development must begin at the grassroots level, reflect local traditions and needs, and gradually build the financial self-sufficiency of the stakeholders as they learn to trust their own wisdom.

Regional Development

Along with MBIS, the other two case studies in the regional development category share an integrated approach to achieving sustainability. Integrated assessments synthesize information from many sources to identify current stresses (unsustainable development factors) as well as the potential for future improvements (sustainability). These programs typically utilize interdisciplinary research groups to provide accurate and pertinent information on key development factors such as the availability and use of natural resources, demographic trends, and social and economic conditions. The resulting information base is then used to build and compare long-term alternative scenarios for future development, and to assess the relative sustainability of each option. Stakeholder participation was made a priority in all of these projects, with emphasis on building networks and strategic partnerships to gain access to and leverage a greater range of talents and resources.

4. Projeto ARIDAS (Brazil)

Funded by the World Bank with additional support from the Brazilian federal and state governments, Projeto ARIDAS was undertaken in the semi-arid, drought-prone Northeast of Brazil from 1992 through 1995. The subject region encompassed nine states and a population of about 40 million people. During periods of drought, residents left the Northeast in large numbers, settling in the Amazon basin and contributing to the depletion of the rain forest, or relocating to the large cities of the South, adding to their unemployed populations. The purpose of ARIDAS was to correct these problems by creating environmental and economic sustainability in the Northeast.

ARIDAS utilized government agencies, NGOs, citizen participation, academia, and non-profit institutions to establish a broad-based sustainable development initiative linking the national government, the governments of the Northeast states, and the citizenry. The project addressed a wide range of issues including drought response, soil erosion, farming techniques, unequal land tenure, water management, education, sanitation, health, lack of infrastructure, and industrial development. Working groups were organized around specific topics, and the integrated methodology required members of the planning teams to update and synthesize previous studies and to coordinate information across disciplines.

The result was a methodology applicable not only to the Northeast of Brazil, but to other semi-arid regions of the world. The proposed development strategy emphasizes major improvements to water management and rebuilding the regional economy around strengths and opportunities unique to the region itself. In the year following the completion of ARIDAS, state governments in Northeast Brazil have begun to implement project recommendations.

5. Rio Grande/Bravo Coalition (U.S./Mexico)

The sharing of fresh water resources across political boundaries has historically been a source of conflict. Over the past several decades, the Rio Grande basin (*Rio Bravo del Norte* in Mexico) in the boundary area between the United States and Mexico has been subject to dramatic changes including the establishment of industry in the region, a rapid increase in human population, and increasing competition for water resources between irrigated agriculture and cities. In 1991, the Houston Advanced Research Center (HARC) convened a conference to discuss the potential impacts of global warming at the regional level. Following the conference, participants from the Rio Grande basin, after discussions with local residents, decided that focusing on water and development, rather than on future climate change, would be more responsive to the sense of urgency shared by citizens of the region. Consequently, an agenda was set to investigate the future availability of water and future economic changes throughout the basin, and the interaction between the two.

It was evident to the researchers that for any practical benefit to be derived from their effort, alliances with local stakeholders were essential. Therefore, HARC facilitated the project not in a conventional research mode, but by

developing local and region-wide citizen groups. Over time, seven such groups were created in major population centers along the river, all establishing their own programs, but also all working together to develop basin-wide initiatives. Because the Rio Grande, for half its course, forms the border between Mexico and the United States, several of these stakeholder groups have binational membership, and aboriginal peoples also participate. In 1994, a decision was reached to form an international, basin-wide NGO based on the understanding that natural resources do not recognize political boundaries. The establishment of this NGO provided the administrative, political, and logistic mechanisms to organize a vast network of information, interests, and stakeholders on both sides of the border, increasing the effectiveness of the original citizen groups by assisting them to develop their own projects throughout the Rio Grande basin.

Technology-Based Sustainable Development

6. Solar Electric Light Fund (China)

The Solar Electric Light Fund (SELF) is a non-profit charitable organization based in Washington, D.C. Its mission is to promote and facilitate the use of non-polluting solar energy systems for rural electrification in developing nations. In one area of rural China, SELF brought solar energy into the homes of Chinese cattle herders and agricultural peasants by leveraging initial seed money from U.S. donor agencies into a sustainable revolving credit fund which, in turn, enabled local stakeholders to purchase the solar energy systems.

One of the first barriers that SELF-China had to overcome was the Chinese Electrification Authority, which viewed SELF as a competitor and refused to release maps showing gaps in coverage in the national electrical grid. Other barriers were financial and cultural: each solar energy panel cost the equivalent of five months of income for the average rural Chinese household, and SELF had to overcome skepticism regarding the efficacy of solar technology.

Although SELF's example demonstrates that solar power can be an appropriate technology to meet the energy needs of rural areas in developing countries, the larger lesson is that an entrepreneurial attitude and creative financing can overcome an initial lack of funding, institutional opposition, and local skepticism.

Empowering Stakeholders

7. Narmada Bachao Andolan (India)

The story of the Narmada Bachao Andolan is different in many ways from the other case studies in *The Road to Sustainable Development,* because it is not about how to plan and implement a service or production-oriented project, but rather how to initiate a movement to resist the implementation of a nationally or internationally funded mega-project felt by local stakeholders to be inimical to their interests.

After years of planning and negotiations between the Indian state governments of Gujarat, Maharashtra, and Madhya Pradesh, construction was ready to commence on the Narmada Valley Project, a major hydroelectric project. Yet, during the entire planning period, no one had thought it necessary to consult with the people that would be most affected by the project: the thousands of peasants and tribal members who would be displaced from their ancestral homes and resettled in new, often hostile, surroundings.

Groups of committed activists were determined to fight the combined power of the state governments, the international funders, and other vested interests in securing for the displaced persons an adequate and just compensation. This determination started a movement which spurred intense debate about conventional top-down development planning, and wide-ranging institutional reviews of the environmental and human rights impacts of large hydroelectric projects.

Central to the success of the Narmada activists was their ability to mobilize the real stakeholders (the displaced people) into action. Through many public meetings in which the stakeholders were given explanations of their rights, and by filing on behalf of the stakeholders legal appeals in the Indian courts, NGOs eventually succeeded in mobilizing stakeholders to resist the hydroelectric project.

The Narmada initiative was a complex protest involving confrontation at many levels which was intended to achieve maximum impact. Grassroots mobilization was important and integral to gaining momentum, but equally, if not more important, was the media focus the activists were able to attract, especially at the international level. This was achieved through the staging of mass demonstrations by entering into strategic alliances with international environmental and human-rights groups, notably the U.S.-based Environmental Defense Fund and the U.K.-based OXFAM.

MBIS and Sustainable Development

Although it does not directly concern a planned economic development, MBIS was selected for analysis in *The Road to Sustainable Development* because it has all of the characteristics essential for a successful sustainable develop-

ment model. Changes in the regional climatic regime resulting from global warming would have far-reaching consequences for the traditional subsistence lifestyle of aboriginal people, as well as major financial and logistic implications for regional economic development activities relating to such areas as agriculture, fisheries, timber, mining, and energy. A systematic, rational strategy to mitigate the adverse impacts of long-term climate change would have to be sustainable in the same manner as a workable, long-term solution to a major economic development initiative.

In either case, the planning and implementation of a sustainable response would have to be coordinated among all levels of government, the private sector and the citizenry; and clearly, the stakeholders who would be affected most directly by the problem would have to participate directly in formulating the solution. In the case of MBIS, these stakeholders are the Native or aboriginal peoples who live in, and depend upon, the Mackenzie River Basin for their physical, economic, and cultural survival.

International attention to global warming, along with the need for strategic thinking about natural resource development options in Canada, were important factors in persuading the Canadian government to initiate MBIS. Record-breaking high temperatures during the 1980s, culminating in the North American Plains drought of 1988, sparked many studies on global warming in Canada.[6] Most of these initial exercises were sectoral studies focusing mainly on southern Canadian interests. In the spring of 1989, however, the Canadian Climate Centre's Arctic Meteorology Section (now the Arctic Adaptation Division) made a commitment to an initiative for a regional impact assessment of global warming scenarios.[7]

The Mackenzie Basin watershed was chosen for this study by the Canadian government because it is vital for hydroelectric production, fishing and inland water navigation. The Basin is the twelfth-largest drainage area in the world and the largest North American river basin emptying into the Arctic Ocean. There are many aboriginal communities along the region's lakes, rivers, and coastline, and the people follow a traditional subsistence lifestyle, linked to the land and its attributes, which makes them particularly vulnerable to the effects of climate change.[8]

Led by Environment Canada and funded primarily by the Canadian Green Plan at a cost of $CAN 950,000, MBIS was a six-year program aimed at assessing the potential impacts of global warming on the region and its inhabitants.[9] Its organizers intended that MBIS would offer planners and stakeholders a new approach for assessing regional problems and finding solutions, one which would take into consideration the views and opinions of all those interested in the long-term outcome. To an unprecedented degree, this goal has been met.

Organizational Structural of MBIS

All efforts of MBIS were coordinated by the MBIS Interagency Working Committee and the MBIS Advisory Group, both established in 1990. These entities consisted of representatives from the federal, provincial, and territorial governments; universities; NGOs representing aboriginal communities; and representatives from the energy sector.

At the heart of the MBIS organizational structure were interdisciplinary working committees. These committees brought together scientists, government officials, business leaders, and aboriginal communities to assess the potential effects of climate change. In large measure, the success of MBIS resulted from the work of these committees in integrating data from the physical, biological and social sciences with information from the aboriginal people, government, and the business sector.[10]

In addition, aboriginal NGOs were crucial to the project. By helping determine not only which aspects of the environment would be studied, but also, in many instances, the scope of the study, these organizations helped to ensure that the scientific studies addressed local peoples' concerns. In some cases, NGOs institutionalized certain controls and formalized the groups' legal rights to final research products.[11]

MBIS as a Model for Planning Future Sustainable Developments

MBIS provides an excellent model for government agencies and NGOs interested in planning sustainable development projects. It is especially useful in demonstrating how to organize and plan an integrated assessment involving many diverse groups. Some of the special features of MBIS include:

An Open-Ended Assessment Approach: MBIS uses an open-ended assessment approach in which various stakeholders can provide input on the research project as it progresses.

Science-Policy Interconnectivity: The MBIS methodology reconceptualizes ways in which science can be communicated to, and used by, the public. An inherent requirement of MBIS is the development of results that are "user-friendly" for policy-makers and community leaders.

Partnerships: MBIS brought together government, academia, the business sector, NGOs, and aboriginal communities to participate in planning, policy, and research activities. The Mackenzie Basin contains a substantial aboriginal population. Inuit (Inuvialuit), Athabaskan (people of the Dene Nation: Slavey, Dogrib, Chipewyan, and others), and Algonquin (Cree, Chippewa, and others) are the main groups which constitute the majority of the aboriginal population of about 50,000 in the total Basin population of roughly 200,000.[12]

Scenario Modeling: MBIS developed four practical scenarios of climate change, linked to population and economic growth scenarios, that project the simulated impacts of alternative future climate regimes on the region and its people.

Policy-Driven Inputs: MBIS priority initiatives focus on practical policy issues:

1. interjurisdictional water management;
2. sustainability of aboriginal lifestyles;
3. economic development opportunities;
4. buildings, transportation, and infrastructure; and
5. sustainability of ecosystems.

Mathematical Modeling: This method provides an analytical approach toward solving complex multi-faceted problems. Such problems cannot be solved using standard assessment methods, which can deal only with simple linear problems.

Integrated Modeling of Human, Biological, and Physical Factors: Global warming would affect not only ecosystems, but also the lives of the people who live in and are an integral part of those ecosystems. The Mackenzie Basin is first and foremost a natural-resource-based economy.[13] The land and water provide virtually all the available resources for the people of the Basin. Changes in patterns of availability of natural resources would perforce result in changes in the traditional practices of the aboriginal people. Accordingly, the sustainability of both the ecosystems themselves and the traditional lifestyles of the aboriginal people who are part of the Mackenzie Basin ecosystems is the primary focus of the integrated model used by MBIS.[14]

MBIS as a Case Study

Our case study of MBIS is based on the examination of project reports; census materials; regional, national, and international journals and newsletters; interviews with project scientists and residents of the Mackenzie Basin; and MBIS interim reports and other products of the MBIS working committees.

In this analysis we emphasize several features of MBIS, particularly those aspects which might be of interest to NGOs intending to participate in sustainable development projects. Besides reporting some of the more interesting findings of MBIS, the purpose of this analysis is to explain how and why members of the MBIS project team carried out their research in the way that they did. It is our intent to share with the reader what appears to be a promising new approach to addressing and solving complex problems of regional significance, so that communities and NGOs worldwide might adopt and utilize the MBIS methodology to assess issues pertinent to them.

In the case study provided for our submission to the US Department of Commerce, we: 1) reviewed the general methodology employed by the MBIS participants; 2) summarized some of the findings: potential impacts of global warming on Mackenzie Basin ecosystems, including aboriginal communities; 3) explained the role played by northern-based NGOs in shaping the impact studies; 4) examined characteristics of Native settlements; 5) looked at how the MBIS researchers interacted with local stakeholders to gain insights into their views regarding global warming; 6) examined some perceptions of MBIS by aboriginal participants; and 7) closed with some insights regarding how participants viewed MBIS, what they considered to be its most useful aspects, notably its phased approach to integrated assessment, and some of the criticisms offered. The report concluded with a list of "lessons learned."

In the following sections, we focus on items 5–7, the consultation process and perception of MBIS.

Global Warming Impacts on Ecosystems and Aboriginal Peoples

The potential impacts of global warming on the Mackenzie Basin would have far-reaching consequences. Aboriginal communities that have lived in the region for millennia and whose lives depend on the land and renewable natural resources could see an end to their traditional lifestyles. Caribou, moose, muskox, muskrat, beaver, waterfowl, and fish, among other wildlife, help to sustain the lifestyles these people have maintained for so long. Yet, a slight change in climate could make this traditional way of life disappear.

It is for these reasons that aboriginal organizations in northern communities became involved in the earliest stages

of MBIS. These helped to determine not only which aspects of the environment would be studied, but also, in many instances, the scope of the studies, thus ensuring that research would emphasize those areas critical to the aboriginals' future sustainability.[15]

At first, project scientists were apprehensive of this aboriginal organization involvement, fearing that some research topics advocated by the aboriginal organizations did not represent the types of approach on which scientific studies have conventionally been based. However, since aboriginal people knew best the intricacies of their regional environment and its importance to their communities, this initial reluctance was soon transformed into an appreciation of their contribution. In many cases, researchers obtained detailed information on the environment even before commencing their studies.[16]

Participatory Processes and Aboriginal People

The NWT consists of many different groups of aboriginal peoples and Native communities, speaking different languages and maintaining different cultural traditions. Part of the challenge for modern Canada lies in the ability of governments at various levels and NGOs to work in concert with these culturally diverse people.

The MBIS approach is instructive for organizations and communities seeking a process that does not take the conventional "top down" attitude to assessing the impact of important issues such as global warming. NGOs' planning and implementing processes can benefit greatly from the multiple viewpoint approach offered by a fully participatory methodology such as that advanced by MBIS. Whether the focus of the project is resolving environmental contamination within a local community or redeveloping a town, city or region, a participatory process can improve the chances of its success.

One aspect of this participatory process for MBIS entailed obtaining input from the aboriginal people. For MBIS researchers the process of working with aboriginal and Native stakeholders had many cultural barriers. Accustomed to communicating with paper and pen, researchers had to learn how to relate ideas through storytelling. This process is referred to as the *transfer of traditional knowledge.*

According to Terry Zdan of Alberta Environmental Protection, to participate in this form of communication it was first necessary for MBIS researchers to establish confidence with community leaders. This process, which often required weeks or even months, was a necessary first step to ensure access to the ideas and recommendations of aboriginal inhabitants.[17]

According to cultural consultant John Newton, the MBIS method of working with aboriginal people had little precedent, and there were no established rules on how to approach interactions with Native stakeholders. In preparing for his trips to the NWT, Newton contacted and spoke with as many people as possible who were familiar with the lifestyles and protocols of northern Mackenzie Basin communities. Although he was able to gather some knowledge of what to expect prior to entering the settlements, he conceded that there were still many elements of his research that had to be left to trial and error.[18]

Newton observed that he was ill-received when people in the community mistook him for a representative of the outside government. Many of the aboriginal stakeholders view the government as unsympathetic and interested only in making NWT settlements the subject of seemingly callous research. Newton also stressed the necessity of weaving oneself into a community prior to, and during, interaction with the aboriginal inhabitants. Partaking in local recreational activities was one way of accomplishing this. Newton refers to it as networking. Doing so enabled him to become a familiar face within the community. Being able to tell potential interviewees that he was referred to them by one of their friends made the outreach process less difficult. Most of all, by participating in local activities, Newton demonstrated that scientists are concerned not just with producing "research" but are also interested in people's daily lives and culture.[19]

Through the interviews he conducted, Newton discovered that there were essentially two types of storytelling prevalent in the NWT. In some cases the stories were straightforward and in direct response to the questions asked. In other cases, the form was more abstract and required much subsequent thought and interpretation.[20] According to Terry Zdan, deciphering the latter form entailed taking information previously heard and making inferences by relating it to the new information.[21] This process of data integration was similar to the way that many of the aboriginal people form their perceptions: through stories that are passed down from generation to generation.[22] According to Zdan,

> For some, the concept of probability can be tossed right out the window. Their perception of what will happen in the future is influenced solely by what has happened over the long run in the past. If there is a change of the long-term effects of fires and floods, then their perceptions of the fires and floods and their stories about the frequencies and characteristics of fires and

> floods will change. If permafrost melts, erosion occurs, and their fishing industries change, then their stories will eventually change.[23]

Engagement in this process can provide useful information beyond what researchers might acquire from merely studying the outward or quantifiable characteristics of aboriginal communities, including the capability of aboriginal people to deal with climate change. Unfortunately, this transfer of traditional knowledge eludes much of the mainstream discourse on global warming today. Zdan believes it should not.[24]

Aboriginal Peoples' Perceptions of Global Warming

Through interacting with the aboriginal people of the Mackenzie Basin, MBIS researchers were able to learn stakeholders' perceptions of the global warming issue. In one such case, Dave Aharonian from the University of Victoria conducted research on the people of Aklavik. His findings revealed that the people of Aklavik feel that both winter and summer are warmer than they used to be, that weather variability is greater now than before, and that changes between each season have also become less consistent. When asked if they were familiar with the concept of global warming, however, the majority of Aklavik residents interviewed asserted that while they had heard of this phenomenon, they were unfamiliar with what it really was.[25]

According to Aharonian's reports, while most Aklavik residents own television sets, print media are almost completely lacking. In addition, most of the region's inhabitants have only a limited formal education (50 percent possess less than a ninth grade education). These are thought to be the two major factors contributing to Aklavik's unfamiliarity with global warming.[26] Aharonian points out that this lack of knowledge regarding global warming is not due to an absence of concern by Aklavik residents with information from the outside world, but because news from the outside world is simply subordinate to local community issues and activities unique to their own aboriginal culture.

Although Aharonian's study indicated that many people in Aklavik were unfamiliar with the concept of global warming, it did not suggest that in general northern Canadian residents are unconcerned about the future of their environment. Many aboriginal peoples of the Mackenzie Basin, in particular the Inuvialuit, Gwitch'in and Dene, have powerfully expressed their concerns over environmental issues for many years. MBIS strove to include the voices of these local stakeholders, and working committees included representatives from these aboriginal groups who substantially contributed to decisions regarding MBIS research projects and goals.

Though opinions and perceptions about the outcomes of MBIS varied at times, one thing became clear: aboriginal people are concerned about the potential impacts that global warming could have on their environment. Barney Masuzumi, the band manager of the K'asho Got'ine Community Council, a part of the local governing apparatus, described to this interviewer a startling incident in which a young man fell through the ice in a small channel. In the past this channel would have been frozen solid at 40° below zero Celsius. Masuzumi said that the local community knew something was occurring around them and took this tragedy as a warning that if a small channel is not frozen in winter, the rivers and lakes would not be frozen either. Using traditional knowledge about their region, the community inferred that their environment was changing in some as yet inexplicable way.[27]

Researchers should be aware that many aboriginal communities monitor important local resources through a great variety of sophisticated methods. These communities assess their renewable resources — such as caribou, muskox, and fish — either by traditional approaches or (since many aboriginal people have attended universities in Canada, the United States, and abroad) through modern "university" methods. Richard Binder, a member of the Inuvialuit Game Council, explained to one interviewer that researchers in his community monitor wildlife such as the beluga whale. The Inuvialuit use satellite technology for that purpose and radio tagging to monitor the movements and distribution of arctic char, an important subsistence fish of the Mackenzie.[28] According to Binder, data on the local environment are stored in many local communities. For instance, Binder explained that the Inuvialuit have amassed a modest database on a variety of environmental issues. Of course, not all aboriginal communities are concerned specifically about the issue of global warming. Most are, however, concerned about climate change through its effects on their daily lives.

Interestingly, this same Inuvialuit culture, which makes use of modern equipment, also maintains its aboriginal traditions. Many Inuvialuit people still hunt the beluga whale as did their ancestors over 5,000 years ago. Because of their intimate relationship with the land and sea, the people and the environment in this region are virtually inseparable. Richard Binder strikingly illustrated this point with a story about his 60-year-old aunt, who killed a seven-foot polar bear the previous winter.

Aboriginal Stakeholders' Perceptions of MBIS

Any discussion of MBIS and aboriginal stakeholders must take into account the following points:

1. The Mackenzie Basin with its climatically sensitive ecosystems will be one of the first regions in the world to suffer in the event of a persistent climate change.
2. The aboriginal communities will have the most to lose if such a climate change occurs, because:
   a) most depend on natural resources such as caribou, moose, fish, and whale to support their traditional subsistence way of life; and
   b) the small population and harsh climate of the NWT make it unattractive for economic development; hence renewable natural resources are, at present, the only means of survival for aboriginal peoples.
3. Attempts to impose unwanted policies on the NWT will meet social, political, and economic resistance from aboriginal communities. Examples from the past include:
   a) the 1975 James Bay Agreement, which compensated aboriginal communities for social and ecological impacts suffered from the installation of the James Bay Hydroelectric Project[29] and
   b) the political turmoil from the Mackenzie Basin pipeline initiative, which was successfully resisted in the 1970s, in part through efforts of the Dene Nation.[30]

Our interviews with four representatives of aboriginal communities revealed their views about the MBIS process. The foremost consideration was respect for aboriginal cultures and knowledge. To successfully conduct research in an aboriginal community, one must personally visit; no e-mail, fax, or telephone call will suffice. Second, ensuring adequate participation of local stakeholders is challenging work and may require a substantial time commitment. A researcher should not expect to enter an aboriginal community and begin his/her research without full acceptance within that community, particularly by its leadership. To this end, MBIS included, along with scientists and private sector and government representatives, several members of aboriginal communities in its governing Interagency Working Committee (see **Table 2** in S.J. Cohen's "Results and Reflections" in this volume). The MBIS coordinators also invited representatives of aboriginal communities to all of the regional workshops and conferences.

MBIS received accolades for its inclusion of local representatives from three of the four aboriginal representatives interviewed for this case study. The other interviewee felt that MBIS failed to assure that aboriginal participants' viewpoints received the same weight as the scientists'. Two of the four interviewees indicated that the traditional knowledge of aboriginal people needs to become as "valuable" as any outside knowledge. These two interviewees hoped to see more funding being directed at understanding and utilizing traditional knowledge. Another concern raised was that representatives of MBIS were visiting local stakeholders too infrequently to update them. In addition, they were not allowing local stakeholders' input into the agenda of the local visits as well as into other aspects of the research process. In short, these aboriginal interviewees sought equal status for their communities in MBIS.

According to Carol Mills, Manager, Lands and Environment for the Dene Nation, the nation is seeking self-determination and wants to make important decisions in its regions, whether they are on policy or research issues.[31] The Dene Nation has published academic papers on the issue of research for local communities, indicating that outside researchers will henceforth have to negotiate their projects with the community of interest. Clearly, the Dene Nation and other aboriginal peoples are deeply concerned about intellectual property issues and the interpretation and usage of traditional knowledge.[32] In the past, researchers have come into a community and extracted traditional knowledge, never to return, while personally gaining status and rewards for that knowledge. Such methods are unacceptable to the Dene Nation. To this end, the Dene have developed a model research agreement for their communities. This model is intended to ensure that any research conducted will be equitable and beneficial to all. The agreement allows communities to negotiate the objectives, scope, and methods of the research project, community training and participation, information management, privacy, communications, benefits, and funding. There is even a clause that can require the researcher to leave if the community believes the agreement has been violated.

Carol Mills believes that the way in which MBIS developed was not altogether beneficial to aboriginal interests. Nevertheless, she believes that the concept of participatory involvement is sound.[33] According to two interviewees, research initiatives in the Northern River Basin and Arctic regions present good examples of participatory research efforts. Ms. Mills and the other three interviewees explained that many aboriginal and native cultures traditionally functioned in a participatory manner and many still do.[34] They cited the band, tribal, and local

councils as examples of the participatory approach to decision making. Still, according to these individuals, the outside culture's compartmentalized approach has slightly altered some aboriginal cultures' decision-making mechanisms.

Despite these and other criticisms of MBIS, it must be emphasized that positive feedback from aboriginal stakeholders and participants far outweighed the negative. MBIS was one of the first major initiatives of its kind in the world; like Projeto ARIDAS in Brazil, it emphasized the inclusion of local and regional stakeholders in decision making.[35]

Conclusion

MBIS has received international acclaim for its phased, participatory approach. This was a process in which efforts were made to explain the potential impacts of global warming to all stakeholders even before the project started. Unlike projects that are conventionally initiated and planned in isolation from local stakeholders, then implemented with little community support, MBIS used an open-ended approach which allowed stakeholders to provide direction from the very beginning. By articulating a clear and widely accepted definition of the problem, and by going to the various potential stakeholders and asking what these issues could mean to them, the MBIS organizers were able to get people accustomed to the idea that "global warming" was *their* problem. This strategy allowed MBIS to develop a research plan openly with all participants in a democratic decision-making process.

Traditional economic development theory is undergoing change in its application to developing and developed countries alike. Even the World Bank has begun to change its development methods. MBIS represents a major effort to create and apply a new approach to resolving issues important to stakeholders and helping communities to plan successful development initiatives.

Has MBIS failed in the eyes of the aboriginal and native people? A more comprehensive study will be necessary to answer that question. However, what MBIS does successfully represent is an example for NGOs, government agencies, and the private sector to study and understand.

In closing, we relate a story of how individuals, no matter what their origin, can enlighten others. This story comes from Barney Masuzumi, the band manager of the K'asho Got'ine Community Council:

> A graduate researcher, with a university-approved research proposal, approached the leader of the community which she was interested in researching. The leader may have appeared to be "out of the bush" — primitive and uneducated — to the researcher. Yet, after the researcher precisely explained her methodology and plans, the community leader asked her one question: "What are your assumptions?" This questions stunned the researcher; she was at a loss for words. Aware of her confusion, the leader asked the researcher to stay in the community for awhile to understand how it operated, and then to re-examine her proposal. After several months, the researcher returned to her university. Some time later, she came again to the aboriginal community with a new proposal of such quality that it received one of Canada's most prestigious research grants.

By asking one simple question, the leader of this community compelled the researcher to re-evaluate her perspective and to view the aboriginal culture through a different lens. This example illustrates how the participatory process is utilized by aboriginal and native communities, and reminds us of the maxim concerning the judgment of others.

Lessons Learned

1) The best possible analysis should be devoted to deciding the important issues (goals or criteria) for a project or initiative. Goal setting is crucial to any assessment approach if it is to produce accurate and effective outcomes. Also, the greatest possible range of goals should be considered, so that concerns of members of a community or region are not locked out of the assessment. MBIS dealt with this concern by always including aboriginal people and other persons who had a stake in the decision-making process.

2) Sustainable development projects benefit from input from a variety of different players. MBIS included representatives of the local, territorial, and federal governments, along with academics, the private sector, and aboriginal people.

3) While an open-ended assessment approach using varied inputs from many participants has major advantages, it must be cautioned that managing such a study can be fatiguing. This fatigue must be anticipated and offset through careful preparation and management.

4) The use of mathematical and scenario modeling can aid governments and communities to assess complex problems and issues in a most profound way. Through these methods, MBIS found that the relationship between the aboriginal people and the environment is very close and sensitive: change one and the other is affect-

ed.

5) If an aboriginal community is assisted to become "modern," it can also become more vulnerable to changing conditions. Within a generation or two, the people may lose their traditional survival skills when they join the wage economy, only to discover that local businesses are too tenuous to support them on a consistent, long-term basis. For most aboriginals, only the land and their traditional wisdom can be trusted to do this.

6) To maximize the usefulness of database information, there must be compatibility between the database and the various data acquisition systems under consideration. In an interdisciplinary project such as MBIS, scientific data are useful only if they can be incorporated into the existing database for analysis and synthesis. Hence, the establishment of a common data platform should be one of the first research and planning considerations.

7) Stakeholder participation should not be underestimated, either with respect to its value or with respect to its administrative and logistic challenges. Success in stakeholder participation requires a great deal of planning and, most important, honoring commitments once they are made. With many stakeholders, conventional methods, such as imposing an inflexible meeting agenda, are unproductive and can lead to the erosion of cooperation between stakeholders and project sponsors.

8) Though e-mail and other means of long distance communication are helpful, there is no substitute for personal contact. Frequent and informal meetings should be a regular part of the whole process.

Epilogue

The Final Workshop of MBIS was held on May 4-9, 1996. We were invited to Yellowknife, NWT, to participate in these final proceedings. Attending the workshop were scientists, consultants, and government officials from Australia, Finland, Germany, and the United States, among other countries. Several aboriginal groups were also represented: Inuvialuit, Métis, Gwitch'in, and Dene. Stewart Cohen, the originator of MBIS, presided over the workshop.

The proceedings confirmed that global warming was a universal and pressing issue among the participants, all of whom expressed concern about climate change in the Mackenzie Basin. Most notable, however, was the emotional intensity with which the aboriginal and Native representatives expressed their concern about climate change and its potential effects on their communities. One Inuvialuit representative powerfully expressed the significance of the land, fish, and wildlife to his people and culture, and the impact that climate change or poor conservation strategies could have on his community's traditional way of life. It became quite clear to us at the workshop that the aboriginal and Native communities were intimately linked with the environment. If the environment suffered, so would the people.

The Western Perspective

MBIS started as an integrated scientific and technical assessment, but evolved into a scientist-stakeholder collaborative effort. Over the course of this six-year scientific study, MBIS researchers came to recognize the importance of the aboriginal stakeholders in the assessment process. The scientists needed essential input from these stakeholders to improve the efficiency and outcome of their analyses. At the same time, they discovered that it was not always easy to obtain this input, and that stakeholders had to be met on their own terms, in ways that first established trust. Stewart Cohen concluded in the workshop's final presentation that "scientist-stakeholder collaboration requires continuous effort, including direct contact." (This latter remark pertains to using personal communication instead of e-mail or fax.)

The most enlightening discovery from the MBIS Final Workshop was the significant interest of the aboriginal and native communities in potential climate change and its impacts. When MBIS began, six years previous to the workshop, the inclusion of aboriginal people in the project was inadequate. With the passage of time, and particularly after strong concerns were voiced, the project structure and, inevitably, its scope, were changed to include more aboriginal voices. The program managers also realized that no single agency (such as Environment Canada in this case) could single-handedly respond to the volume of research collected or to the policy challenges which the research presented.[36] A regional or worldwide problem such as global warming requires the participation of a great diversity of stakeholders, not only from different levels of government, but also from the potentially affected communities and regions, NGOs, and the private sector.[37]

The Aboriginal and Native Perspective

As stated earlier, the relationship between the aboriginal and native communities and the land is intimate and substantial. The aboriginal representatives all expressed a

shared concern over environmental degradation and its effects on their traditional lifestyles. They explained, for example, how their communities had suffered when river contaminants had reached the communities of Yellowknife, Fort Simpson, and Inuvik. They realize that fish, wildlife, and plants which have long been essential to their physical and cultural survival may disappear if their region becomes warmer as a result of persistent climate change.

The aboriginal communities value the land and its resources because of all that these resources provide for them physically But the traditions that their ancestors began thousands of years ago are of defining importance to their cultures. In was in this context that the significance of traditional knowledge became evident during the workshop. A concern repeatedly expressed by aboriginal representatives was the importance of including traditional knowledge in MBIS and future projects pertaining to them. They emphasized that the lasting effectiveness and value of a project will benefit greatly from the inclusion of traditional knowledge, because the land and its people are inextricably connected. The intense sincerity with which aboriginal participants expressed the importance of their inclusion in projects like MBIS is easily explained: It is the stakeholders who must live with the outcomes.[38]

Notes

1. A note on terms: In Canada, a distinction is made among the terms *aboriginal, indigenous,* and *Native* by some groups. In this report we have made an effort to recognize and honor that distinction, albeit imperfectly. If a term is used incorrectly or out of context, it should be considered to represent the most appropriate terminology.

2. Lyndon B. Johnson School of Public Affairs. 1996. *The Road to Sustainable Development: A Handbook for Citizens.* Draft Chap. 1: Down the Long Road. Austin, Texas: Univ. of Texas at Austin, p. 14.

3. Holling, C.S., ed. 1978. *Adaptive Environmental Assessment and Management.* John Wiley and Sons, New York. 377 pp.

4. Lyndon B. Johnson School of Public Affairs. 1996. *The Road to Sustainable Development: A Handbook for Citizens.* Draft Chap. 1: Down the Long Road. Austin, Texas: Univ. of Texas at Austin, p. 7.

5. *Ibid.,* p. 7.

6. Cohen, Stewart. 1993. Main Report. In Stewart Cohen, ed. *Mackenzie Basin Impact Study: Interim Report #1,* p. 3.

7. *Ibid.*

8. Telephone interview by Joseph Stewart with Joseph Benoit, Gwitch'in Tribal Council, Yellowknife, NWT, May 7-8, 1996.

9. Cohen, Stewart. A Note From the Project Leader. In Stewart Cohen, ed. *Mackenzie Basin Impact Study: Interim Report #1.*

10. Lyndon B. Johnson School of Public Affairs. 1996. *The Road to Sustainable Development: A Handbook for Citizens.* Draft Chap. 1: Down the Long Road. Austin, Texas: Univ. of Texas at Austin, p. 14.

11. *Ibid.,* p. 14.

12. Figures taken from *The Canada Encyclopedia* (Hurtig Publishers, Edmonton: Alberta, Canada), pp. 1212, 1217-1219. Note on terms: According to the Constitution Act of 1982, the aboriginal people are defined as Inuit, Metis and Indians (Dene, Cree, and others).

13. Yin, Yongyuan, and Stewart Cohen. 1994. Development of the MBIS Program. In Stewart Cohen, ed. *Mackenzie Basin Impact Study: Interim Report #2* (November 1994), p. 48.

14. Cohen, Stewart. 1993. Main Report. In Stewart Cohen, ed. *Mackenzie Basin Impact Study: Interim Report #1,* p. 8.

15. Telephone interview by Marcus Dyer with Fred Roots, Environment Canada, Ottawa, March 8, 1996.

16. *Ibid.*

17. Telephone interview by Marcus Dyer with Terry Zdan, Alberta Environmental Protection, Edmonton, Alberta, Canada, March 5, 1996.

18. Interview by Marcus Dyer with John Newton, John Newton Associates, Toronto, Ontario, in Yellowknife, NWT, Canada, May 5, 1996.

19. *Ibid.*

20. *Ibid.*

21. Telephone interview by Marcus Dyer with Terry Zdan, Alberta Environmental Protection, Edmonton, Alberta, Canada, March 5, 1996.

22. *Ibid.*

23. *Ibid.*

24. Telephone interview by Marcus Dyer with Terry Zdan, Alberta Environmental Protection, Edmonton, Alberta, Canada, March 5, 1996.

25. Aharonian, Dave. 1994. "Land Use and Climate Change: An Assessment of Climate-Society Interactions in Aklavik NWT". In Stewart Cohen, ed. *Mackenzie Basin Impact Study: Interim Report #2* (November, 1994), p. 411.

26. *Ibid.,* p. 412.

27. Telephone interview by Joseph Stewart with Barney Masuzumi, K'asho Got'ine Community Council, Fort Good Hope, NWT, Canada, February 3, 1996.

28. Telephone interview by Joseph Stewart with Richard Binder, Inuvialuit Game Council, Inuvik, NWT, Canada, March 13, 1996; *Inuvialuit Harvest Study Calendar* (July 1996 and August 1996).

29. *The Canada Encyclopedia* (Hurtig Publishers: Edmonton, Alberta, Canada, 1985), p. 912.

30. *Ibid.,* pp. 482-483, 1061-1062.

31. Telephone interview by Joseph Stewart with Carol Mills, Dene Nation, Yellowknife, NWT, Canada, March 27, 1996.

32. *Ibid.*

33. *Ibid.*

34. *Ibid.;* Telephone interview by Joseph Stewart with Barney Masuzumi, K'asho Got'ine Community Council, Fort Good Hope, NWT, Feb. 3, 1996.

35. Environment Canada, *Final Workshop of the Mackenzie Basin Impact Study: Abstracts of Paper and Poster Sessions* (Yellowknife, NWT, May 5-8, 1996), p. 16.

36. *Ibid.,* p. 3.

37. *Ibid.,* p. 3.

38. Another important issue that became evident late in our research, during our attendance at the final workshop, was the problem of unsettled land claims by aboriginal communities. This is a pressing and controversial issue for some aboriginal groups. For the Inuvialuit and Gwitch'in, land claims have been settled. This allowed the communities to focus their efforts on developing the necessary infrastructure and training to provide for themselves as sovereign communities. However, for the Dene Nation and others with unresolved settlements, the land claims issue preempts many other problems and initiatives to address matters pertaining to their interests. Because of this preoccupation, the Dene and certain other stakeholders did not participate fully in MBIS. The energy of these communities is focused on resolving this critical issue, and closure is necessary before real advances on the social or economic front can occur. If the land claims are settled, further progress in terms of increased aboriginal participation in regional, provincial , and global affairs will be possible.

10

CASE STUDIES FROM OTHER COUNTRIES

Report on the Bering Sea Impact Study (BESIS)

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I. Prospectus and Pre-Proposals

A 17-page prospectus and call for pre-proposals for the Bering Sea Impact Study (BESIS) was published by the BESIS Project Office in Fairbanks in April 1996 and distributed widely. It resulted in 98 pre-proposals being submitted (see **Table 1**). The BESIS Steering Committee met in August to review the proposals and selected a number of high-priority projects and their proponents for participation in a workshop in September (see item II).

II. BESIS Workshop and Technical Session

The BESIS workshop and a Bering Sea technical session took place during the annual American Association for the Advancement of Science (AAAS) Arctic Science Conference on 18-21 September, 1996 at Girdwood, Alaska.

The BESIS workshop on 18 September was attended by about 50 people, including invited participants from Russia (10), Japan (3), Canada (2) and China (2). Following introductory remarks by Dr. Weller and some discussion, four interdisciplinary groups addressed the following issues:

- Global change and its effects on the physical environment,
- global change and its effects on coastal and marine ecosystems,
- global change and its effects on economic activities, and
- global change and its effects on Native culture and the subsistence way of life.

On 19 September an all-day session of the Arctic Science Conference dealt with Western Arctic/Bering Sea Impact Studies and was chaired by Dr. Vera Alexander from the University of Alaska Fairbanks. Fourteen technical papers were presented, discussing climate trends, oceanography, sea ice, glaciers, permafrost, trace gas release, biota, whales, coastal communities and traditional knowledge. An additional 20-odd posters on similar topics were also on display. Both oral and poster papers showed some of the interesting available data and information that deal with existing and potential global change impacts in the region.

At the workshop on 18 September there were also two brief presentations from funding agencies. Dr. Douglas Siegel-Causey from the Office of Polar Programs of the U.S. National Science Foundation (NSF) discussed that office's programs and interests in BESIS. He stated that to get NSF funds for BESIS a proper science plan needs to be developed. Dr. Boris Levin from the Russian Foundation for Basic Research (RFBR) in Moscow discussed that foundation, and a memorandum was drawn up during the meeting for submission to RFBR, to fund Russian participation in BESIS in 1997.

III. Next Steps

The next step in BESIS will be to edit and publish the workshop report which is expected to take the form of a first rough impacts assessment and an outline of additional tasks. Plans are to conduct the next iteration of the impacts assessment at a workshop in spring 1997, if funding which the BESIS Project Office has applied for from the NSF and private foundations in the U.S. materializes.

Table 1. BESIS Pre-Proposals

By Country	
Russia	55
United States	27
Japan	14
Canada	1
China	1
By Topic	
Physical Sciences	30
Ecology	30
Climate/paleoclimate	11
Pollution	11
Societal	11
Biogeochemical	4
Other	1

Assessing the Consequences of Global Changes for the Barents Region: The Barents Sea Impact Study (BASIS)

Dr. Peter Kuhry and Prof. Dr. Manfred A. Lange

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Global Change: Fact or Fiction?

The world around us is constantly changing. This may not be new to you. Neither may it surprise you that natural processes are responsible for major shifts in climate, the chemical composition of soil, water and air or changes in the number, distribution and composition of terrestrial or marine animals and plants. On the other hand, natural variations seem to proceed at a very slow pace. Thus, why should we be concerned about something that everybody likes to call global change in these days? And what is really meant by this phrase?

Global changes or global environmental changes as they are also often called have to do with us, that is to say with the way man influences and alters the Earth and its various components. For the first time in human history, man takes on an active role in changing the way the Earth works. This can be seen in many ways. For instance, if we consider the composition of the atmosphere or the ocean, we can observe drastic changes. Oil spills or the release of toxic chemicals into the air are but two processes which cause considerable disturbances in the natural environment. Another well-known example is the so called ozone hole (the reduction in ozone concentrations at atmospheric heights above 11 kilometers), which is attributed to the chemical interactions between ozone (a molecule consisting of three oxygen atoms: O_3) and man-made chloro-fluoro carbons (CFCs; the gas in refrigerators and spray cans).

Talking about the atmosphere, the constant release of carbon dioxide (CO_2) through the burning of coal, oil and gas leads to a steady increase of atmospheric carbon dioxide concentrations. This in turn causes temperatures to rise gradually by a process which is known as *greenhouse effect*. We therefore call CO_2 a *greenhouse gas*. Ever since industrial development has taken shape, atmospheric CO_2 concentrations are on the rise and so are global temperatures. Never before in the last 160 000 years have we observed as high an atmospheric CO_2 content as today and global temperatures have climbed by well over half a degree during the last 100 years (**Figure 1**). Temperatures are predicted to rise globally by about 3 to 4.5° over the next 100 years and about twice as much in the Arctic. Measured temperature trends for 1961 - 1990 indicate a warming trend in Alaska amounting to 0,8° per decade or 8° over the next century. And it now is certain that recent changes are due to man's influence and not just another natural climate variation.

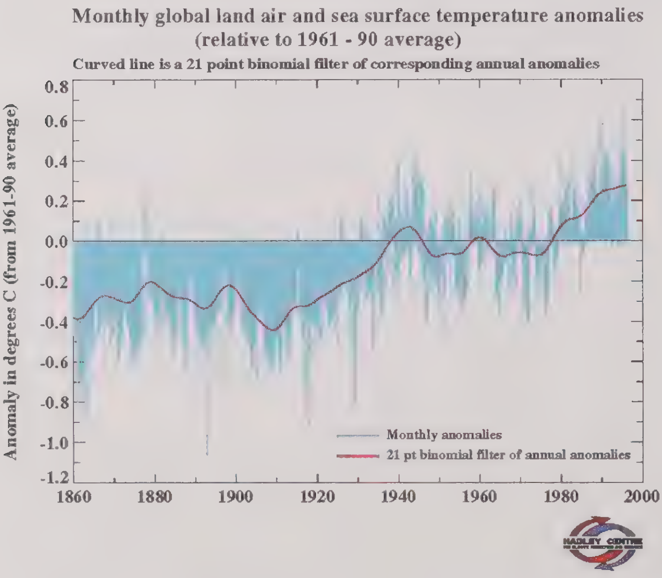

Figure 1: Observed monthly global land air and sea surface temperatures (Source: Hadley Centre, Bracknell, UK)

While this does not seem all that bad (who would not like a few more warm days and a longer summer?), the overall consequences of such changes may be quite severe. Scientist are concerned that global warming may disturb the fragile balance that governs oceanographic processes in the North

Atlantic. Such a disturbance may result in the shut-off of the Gulf Stream which would lead to drastically colder conditions in northern Europe. In addition, it is not only the magnitude of the change of global temperatures as the **rate of change**, which we are experiencing. Many of the animals and plants that we know today will not be able to keep up with such rapid fluctuations. The result will be a disturbance in many natural systems, for instance in forest ecosystems. Yet another, maybe more pressing question is how the people in a particular region of the world will be able to cope with such rapid changes and to what degree they will have to adapt to drastically altered conditions in their environment?

The Impacts of Global Changes: Why should we be Concerned?

The threats posed by global changes have been identified not only by scientists or concerned citizens. The state of the global environment has long entered the political arena. The Earth Summit in Rio de Janeiro, 1992 and the resulting *United Nations Framework Convention on Climate Change* (UNFCCC) provide two prominent examples. The UNFCCC is now a part of international law, committing more than 120 nations to action.

> ***Losers or Winners?***
>
> *Common belief:* The Circumpolar North is likely to gain from a future warming trend, since a warmer climate will allow longer growing seasons, ease transportation in ice-covered waters and enhance forest growth.
>
> *Reality:* Global warming will have positive and negative effects. At present, it is hard to say, what the net effect will be like. However, studies in the Mackenzie Basin, Canada and in Alaska show that the negative effects are not to be overlooked. For instance, warming also means drier summers. This will cause forest fires to increase dramatically (a trend that is already observable in the North West Territories of Canada). This, in combination with equally enhanced outbreaks of forest pests may well override any enhancements of forest growth that may result from global warming.

However, while the proposed mitigation measures by the UNFCCC, which basically call for a stabilization and ultimately a reduction in the emission of carbon dioxide and other greenhouse gases are certainly to be welcomed, it may be difficult to assess just why anybody should personally be concerned. Are not particular nations much more 'guilty' than others in emitting 'excessive' amounts of greenhouse gases to the atmosphere? And what really would a 1 to 3.5° change in temperature mean for a given region?

Answers to such questions are clearly lacking today. This may be the major reason why political support for 'real' actions to be undertaken under the UNFCCC remains forthcoming. Unless people have a clear understanding of the impacts (consequences) of global changes, that is to say they know what is in store for them in their own 'back yard', the willingness to commit themselves to a significant change in their lifestyle will remain slim.

The issues to be addressed can be boiled down to a number of ***"what if"*** questions on the probable magnitude and the spatial as well as the temporal extent of likely changes in earth parameters, which have to be answered by scientific investigations. Answers to these questions will be confronted by ***"so what"*** and ***"what should be done"*** questions *by stakeholders in the region.*

Understanding the impacts of global changes in a region is not an easy chore. It requires a comprehensive approach and an assessment of all elements of a region,

> ***"What if?" versus "So what?"***
>
> *"What if?" - questions: some examples:*
>
> - **Oceanic regime:** what will happen if the Gulf Stream 'shuts off' and what will be the effects for fisheries in the Barents region?
> - **Terrestrial and forest ecosystems:** what if climate change and increased pollution load affect forestry productivity?
> - **Reindeer herding:** what if changes in temperature, precipitation and erosion affects food availability for reindeer?
>
> *"So what?" - questions: some examples:*
>
> - **Ocean regime:** will not changes imposed by political and economic regulations be more important than changes in the fisheries regime as caused by climate variability?
> - **Terrestrial and forest ecosystems:** will changes in technology and forestry practices balance any effects of global changes?
> - **Reindeer herding:** to what extent will altered land use regulations impose additional stress on the conditions for reindeer husbandry?

be it the physical, biological or social properties and of the processes controlling what is going on, This is what integrated impact studies attempt to undertake and this is what the *Barents Sea Impact Study* (BASIS) is all about.

Even the best and most comprehensive of studies will never result in absolutely definitive answers as to the *exact* consequences of global changes for a region. However, without such studies, it will be even harder to evaluate such consequences and to be prepared for them. It is certainly true that other factors, such as regional policy or regional to global economic development will have an impact on the Barents region which may even outweigh any environmental changes as envisioned here. However, to neglect an assessment of possible consequences of global changes and to focus just on politics and economics will leave us with even greater uncertainties when it comes to evaluate future trends and options in the Barents region.

Why the Barents Region?

The Barents region is of particular interest in the context of the Circumpolar North for several reasons. However, before going into these reasons, let us look at the specific geography of this region as selected for BASIS (**Figure 2**). Note that the region includes the northern part of Fennoscandia including parts of Norway, Sweden, Finland, the Murmansk Oblast and the Republic of Karelia, parts of the Archangelsk Oblast, Novaya Semlya, but also Svalbard and Franz Josefs Land. It furthermore includes parts of the North Atlantic, the Barents Sea and a fraction of the Kara Sea.

Looking first at the oceanographic regime, the region embraces, at least partly, the exchange of water masses from the south with those originating in the high Arctic. The Barents Sea is clearly influenced by the input of relatively warm water (a branch of the Gulf Stream), which maintains largely ice-free conditions along the northern coast of Fennoscandia. The Barents Sea is rich in marine life, making it one of the most productive fishing grounds in the Circumpolar North. Thus, it is no surprise to learn that fisheries in the Barents Sea is a major economic factor for Norway and north-western Russia.

The Barents Sea also contains rich reserves of non-renewable resources: natural gas and oil, which are already or are being planned to be utilized. Oil and gas deposits are also found in abundance offshore, along the coast of the Barents Sea in the Archangelsk Oblast, which brings us to the terrestrial realm. The Kola Peninsula contains one of the richest deposits in economic minerals, both in terms of volume but also in terms of variety of minerals found. This has resulted in major development in smelting and refining factories in the northern and central part of the Kola Peninsula and is the main reason for the highest population density within the Circumpolar North. Minerals also figure high on the economic agenda in northern Finland and northern Sweden. However, here as in Karelia and the Archangelsk Oblast, forestry is an even more important factor of the national economies. Tourism on the

Pollution in the Arctic

Common belief: Since the Arctic is only sparsely populated, pollution is not a relevant issue

Reality: Despite its sparse population in general, there are prominent 'point sources' of pollutants to be found in the Arctic. The Kola Peninsula with its thriving metallurgical industry is a prominent example of such a pollutant source. The emission rates of sulfur dioxide from this industry are among the highest rates observed in the whole of Europe. Future industrial exploitation, particularly with regard to the oil and gas industry represents major potential sources of pollution in the Barents region. In addition, pollutants are being brought to the Arctic by prevailing atmospheric circulation patterns during the northern winter months. Measured concentrations in what has been coined 'Arctic Haze' equal or exceed concentrations found in densely populated regions of central Europe.

Figure 2: Geographic boundaries of the region considered in the Barents Sea Impact Study (shaded; see also cover)

other hand is still seen as a major growth area for the northern parts of Norway (including Svalbard), Sweden and Finland with its potential still largely untapped or, in the case of the Russian North-West, not even touched yet. Yet another, historically most important occupation is reindeer husbandry, which is still a major source of livelihood for the Sámi of northern Fennoscandia and the Kola Peninsula as well as for the Nenets people in the Nenets Okrug as part of the Archangelsk Oblast.

This short and by no means comprehensive compilation demonstrates that the Barents region represents one of the economically most developed region in the North with a relatively high number of inhabitants. Changes in major natural conditions, such as climate or the distribution and magnitude of contaminants in the Barents region are therefore to be seen as challenges to local communities and the economic activities in the region. This is why the *International Arctic Science Committee* selected the Barents region (together with the Bering Sea region) as their prime target(s) for cumulative impact studies in the Arctic.

Major Goals: What do we strive for?

The major, overarching goal of the *Barents Sea Impact Study* is to assess the impacts of global changes on cultural and socioeconomic systems dependent on renewable and non-renewable resources in the Barents Sea region.

This ambitious goal can be broken down into the following objectives:

- BASIS will assess the likely magnitude of global environmental (or climate) changes on regional to sub-regional scales in the Barents region; this will include an assessment of past changes as deduced from historical or archeological records.
- BASIS is going to provide insights into the consequences of these changes for terrestrial, freshwater and marine ecosystems.
- BASIS, by taking a comprehensive look at specific economic sectors in the Barents region is going to develop an integrated assessment of global change impacts in the Barents region.
- BASIS will also evaluate possible threats for the well-being of local communities in the Barents region.
- BASIS will try to provide the necessary basis for possible adaptation measures aimed at minimizing the impacts of global changes on the Barents region.

A notion, underlying all of these objectives has to do with a concept called ***sustainable development***. Sustainable development, though defined in many different ways, essentially means that present development and exploitation of natural resources should be pursued only to the extent which does not jeopardize the utilization of these resources by future generations. In order to reach or maintain sustainable development in a region, we must foresee possible threats to natural resources due to changing conditions other than human exploitation. Thus, assessing the integrated impacts of global changes for natural resources can be seen as a prerequisite for sustainable development in the Barents region.

Details of the background for and the major principles to be applied in BASIS (particularly with regard to the integration of individual study results) are given in the BASIS Implementation Plan.

Organization and Functions: How do we work?

The Barents Sea Impact Study is a core project of the *International Arctic Science Committee.* The study is being steered by a Core Group and a Review Committee. Their major task is to define scientific goals and objectives in accordance with stakeholder interests in the Barents Region and to guide the implementation, execution and integration of individual projects.

Projects within BASIS are being integrated through theme groups that address particularly important natural and/or socioeconomic issues in the Barents region. At present, the following theme groups have been specified:

- Changes in ocean climate in the Barents Sea: The impact on fisheries
- Global changes and terrestrial (forestry) ecosystems in the Barents Sea region
- Climatic change and its impact on reindeer herding

Each theme group is organized in a systematic and uniform way as illustrated in **Figure 3** for the theme on *Ocean climate and fisheries.*

As can be seen, we distinguish two basic levels (ecosystem level, human/societal level) and within each level three major environments (marine, terrestrial, physical). Each of the topical boxes represents one or more projects addressing the specific topic(s) mentioned. There will be integration/exchange of information 'horizontally' across the various projects on a particular level as well as 'vertically' for each of the environments considered. The investigations are being 'driven' by specific global change scenarios of relevant parameters (for instance, climate parameters or pollution) with minimal, maximal and mean magnitude. The ultimate goal for each of the theme groups lies in integrated impact assessments for each of the global change scenarios considered. This will allow the estima-

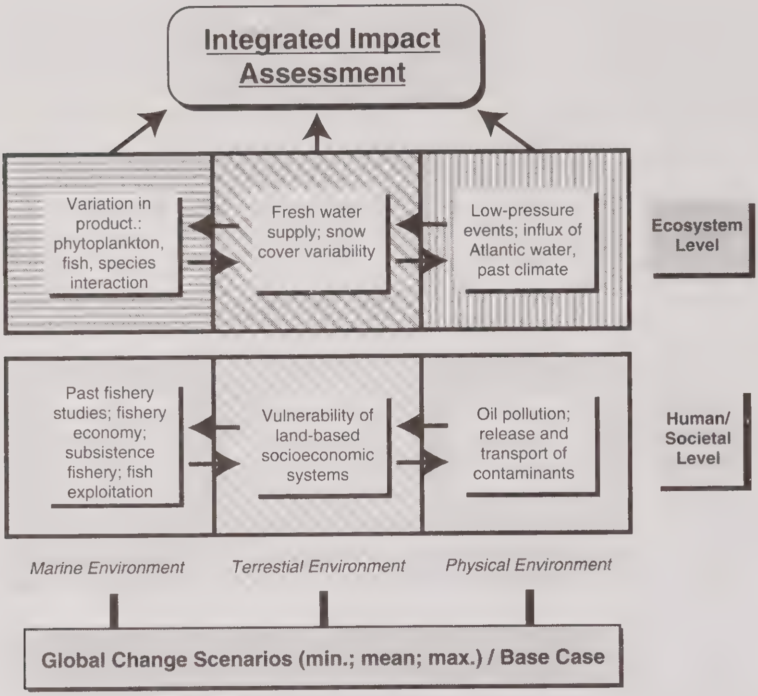

Figure 3: Basic scheme for integrated impact assessment: *Ocean climate and fisheries (arrows denote horizontal or vertical integration)*

tion of required adaptation to changes on a minimum, maximum or mean level of expected future alterations.

The issue of integration, as mentioned above, is central to any attempt towards a holistic impact assessment. There are numerous methodologies that have been employed (for a review, see Yin and Cohen, 1994; Parson, 1994; Shackley and Wynne, 1995). We will build on the experience of our Canadian colleagues which has been gained in the course of the *Mackenzie Basin Impact Study*. Specifically, we will adapt their *Integrated Land Assessment Framework* (Yin and Cohen, 1994). One major prerequisite for such a framework is a geographic information system (GIS) that is commonly used by all of the study participants. Similarly, we will have to develop and implement appropriate means for data archiving , storage and retrieval.

Expected Results and Output: What will be delivered?

What do we expect to deliver during the time BASIS is carried out and after it has been completed? Answers to this question, though still somewhat uncertain, can be summarized as follows:

- BASIS is going to develop specific scenarios for changes in major parameters that drive natural and socioeconomic systems in the Barents Region.
- BASIS is going to initiate and actively pursue a dialog between scientists and stakeholders in the region. This will serve two purposes. On the one hand, it will provide needed guidance on issues to be addressed in the study. On the other hand, communication with stakeholders will raise their awareness for potential implications of global change issues they should be concerned about.
- BASIS will derive integrated impact assessments for (initially) three theme groups, as outlined above. These assessments will serve to develop proactive adaptation strategies for specific socioeconomic sectors and groups in the Barents region.
- BASIS will point out particularly vulnerable economic sectors that are likely to be affected most by global changes. In so doing, we will provide guidance on policy making in the region and goal setting in regional cooperation such as the *Barents Euro-Arctic Council*.

Current state and future plans for BASIS: The way ahead

BASIS has been under active development for about one year. It has been extensively discussed both internally, by the BASIS Core Group and the BASIS Review Committee and externally during the *International Conference on Arctic Research Planning* of the *International Arctic Science Committee*. In addition, BASIS has been discussed and reviewed by the *European Marine and Polar Board* of the *European Science Foundation*.

In Spring of 1996, a Call for *Letters of Intent* was issued and sent out to 500 contact persons in 20 countries. The response was very encouraging, amounting to, as yet, 81 *Letters of Intent*. The Letters were evaluated by members of the BASIS Core Group and BASIS Review Committee

and were extensively discussed by the Review Committee during a meeting in Helsinki at the end of June. As a result of these deliberations, a total of eight projects have been designated as core projects while an additional 28 projects have been assigned a contributing status.

The activities of the immediate future can be summarized as follows:

- The three theme groups selected will be extensively discussed by the BASIS Core Group, the BASIS Review Committee and the principal investigators of the selected core projects and will be developed into a number of proposals. The main target for these proposals will be the *Commission of the European Communities,* however, other funding agencies will be approached as well.
- A workshop in November 1996, jointly sponsored by the *Arctic Climate System Study,* the *European Marine and Polar Board* of the *European Science Foundation* and the *International Arctic Science Committee* will address the issue of arctic regional climate models needed for BASIS.
- During the remainder of 1996, contacts to major stakeholders or representative organizations will be developed. This will partly be facilitated through the *Barents Euro-Arctic Council* and its Regional Board.
- At the beginning of 1997, a first science conference on BASIS will be held, involving the BASIS Core Group, the BASIS Review Committee and the principal investigators of the selected core projects, contributing projects, any other interested scientists as well as major stakeholders or their representatives in the Barents region.

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APPENDICES

Appendix 1: MBIS Final Workshop Program

MACKENZIE BASIN IMPACT STUDY (MBIS) FINAL WORKSHOP

Explorer Hotel, Yellowknife NWT
1996: May 5-8

SUNDAY MAY 5, 2:00 - 4:00 PUBLIC SESSION ON CLIMATE CHANGE

Prince of Wales Heritage Centre

- Walter Skinner, Environment Canada — *Climate Trends*
- Janet Aylsworth, Natural Resources Canada — *Permafrost Thaw and Landslides*
- Rick Lanoville, NWT Fire Weather Centre — *Forest Fires*
- Stewart Cohen, UBC and Environment Canada — *Mackenzie Basin Impact Study*

Explorer Hotel

- 5:00 - 7:00 MBIS registration and icebreaker; set up for poster sessions

MONDAY MAY 6, MBIS FINAL WORKSHOP: DAY 1, 8:30-5:00

- 8:30 - 10:00 OVERVIEW 1: WELCOME, OVERVIEW OF MBIS PROGRAM

Chair: David Grimes, Environment Canada

Lorne Tricoteaux, Indian & Northern Affairs Canada — *Welcome*
Robert McLeod, NWT Renewable Resources — *Welcome*

Stewart Cohen, Environment Canada/ University of British Columbia — *Results and Reflections from the Mackenzie Basin Impact Study*

- 10:00 - 12:00 POSTER SESSION 1 (includes coffee break)

- 12:00 - 1:15 LUNCH

Chair: Ian Burton, Environment Canada

Louise Comeau, Sierra Club — *Partnerships: the key to protecting Canada's interest in the climate change debate*

- 1:15 - 3:15 OVERVIEW 2: INTEGRATED ASSESSMENT

Chair: Stewart Cohen, Environment Canada /University of British Columbia

Yongyuan Yin, Environment Canada/ University of British Columbia	*Land Assessment Framework*
Guo Huang, University of Regina	*Multi-Objective Modelling*
Robert Bone, U. Saskatchewan	*Settlements and Non-Renewable Resources*

- 3:15 - 4:30 POSTER SESSION 2 (includes coffee break)
- 4:30 - 5:00 ROUND TABLE 0: INTRODUCTION TO ROUND TABLES

TUESDAY, MAY 7 - MBIS FINAL WORKSHOP: DAY 2, 8:30-4:30

- 8:30 - 10:30 ROUND TABLE 1: INTERJURISDICTIONAL WATER MANAGEMENT

Chair: Jim Bruce, Canadian Global Change Program and Canadian Climate Program, Ottawa
Rapporteur: Linda Mortsch, Environment Canada, Burlington

Terry Zdan, Alberta Environmental Protection, Edmonton
Robert McLeod, GNWT Renewable Resources, Yellowknife
Brian O'Donnell, Environment Canada, Edmonton
Karen LeGresley Hamre, Gwich'in Interim Land Use Planning Board, Inuvik
Dean Arey, Inuvialuit Game Council , Inuvik

- 10:30 - 12:00 POSTER SESSION 3 (includes coffee break)
- 12:00 - 1:15 LUNCH
- 1:15 - 3:00 ROUND TABLE 2: SUSTAINABILITY OF ECOSYSTEMS

Chair: Ted Elliott, Colorado State University, Fort Collins, Colorado, U.S.A.
Rapporteur: Stephanie Irlbacher, Canadian Polar Commission, Yellowknife

Maurice Boucher, Deninu Ku'e Environment Committee, Fort Resolution
Ron Graf, GNWT Renewable Resources, Yellowknife
George Low, Fisheries and Oceans Canada, Hay River
George Kurszewski, President, Fort Smith Local, NWT Metis Nation, Fort Smith
Kevin McCormick, Environment Canada, Yellowknife
Cam McGregor, Alberta Environmental Protection, Edmonton
Charlie Snowshoe, Elder, Gwich'in Interim Land Use Planning Board, Fort McPherson

- 3:00 - 3:20 COFFEE

- 3:20 - 5:00 ROUND TABLE 3: ECONOMIC DEVELOPMENT

Chair: Rodney White, University of Toronto
Rapporteur: Randall Barrett, Alberta Environmental Protection, Edmonton

Joe Ahmad, GNWT Energy Mines & Petroleum Resources, Yellowknife
Chris Fletcher, BC Ministry of Forests, Victoria
Charlie Furlong, Mayor of Aklavik, Aklavik
Daryll Hebert, Alberta-Pacific Forest Industries, Inc., Boyle, Alberta
Bridgette Larocque, Metis Economic Development Corporation, Metis Nation, Inuvik

Wednesday, May 8 - MBIS Final Workshop: Day 3, 8:30-3:30

- 8:30 - 10:00 ROUND TABLE 4: MAINTENANCE OF INFRASTRUCTURE

Chair: Rod Dobell, University of Victoria, Victoria
Rapporteur: Terry Zdan, Alberta Environmental Protection, Edmonton

Randy Cleveland, GNWT Public Works & Services, Yellowknife
Pietro de Bastiani, GNWT Transportation, Yellowknife
Alan Hanna, AGRA Earth & Environmental Limited, Calgary

- 10:00 - 10:20 COFFEE

- 10:20 - 12:00 ROUND TABLE 5: SUSTAINABILITY OF NATIVE LIFESTYLES

Chair: Whit Fraser, Canadian Polar Commission, Ottawa
Rapporteur: Laszlo Pinter, International Institute for Sustainable Development, Winnipeg

Joanne Barnaby, Dene Cultural Institute, Hay River
Lou Comin, Wood Buffalo National Park, Fort Smith
Herbert Felix, Inuvialuit Game Council, Inuvik
Don Antoine, Denendeh Environment Committee, Fort Simpson

- 12:00 - 1:30 LUNCH

RAPPORTEURS' SUMMARIES OF ROUND TABLES 1 TO 5

Chair: Stewart Cohen, Environment Canada and University of British Columbia

- 1:30 - 3:00 ROUND TABLE 6: RECOMMENDATIONS

Chair: Stewart Cohen, Environment Canada and University of British Columbia, Vancouver
Rapporteur: Pamela Kertland, Environment Canada, Toronto

David Malcolm, Science Institute - Aurora College, Inuvik
Jim Bruce, Canadian Global Change Program and Canadian Climate Program Board, Ottawa
Rodney White, University of Toronto, Toronto
Joe Benoit, Gwich'in Land Administration, Inuvik

Appendix 2: Some Prepared Statements Contributed by Round Table Panelists

From Round Table #4:
Maintenance of Infrastructure

Randy L. Cleveland, GNWT Public Works & Services, Yellowknife

I would like to thank Dr. Stewart Cohen for his invitation for participate in this final workshop. I met Stewart at the very beginning of this project in early 1990 at a conference of the Association of Canadian Universities for Northern Studies, and heard him talk about his new northern project. Just before that, I had attended a departmental management conference in Pond Inlet on the Northern tip of Baffin Island, about 73° North. We had met to discuss the 57 different operational issues that a public works organization always faces, but for a little relief, I had volunteered to give a short talk on global warming. The talk was met with extreme cynicism. It was December 3rd, the day was cast in the perpetual darkness of the Arctic night, it was +3 degrees Celsius <u>and</u> it was raining. Yet this group of highly trained engineers was not prepared to entertain the notion of climate change. Extreme cold in the north seemed to be an inalienable right that would not be dissolved even by rain in December. At any rate, when I met Stewart shortly afterward, I couldn't help but note the coincidence and have retained an interest in his work ever since.

I have mentioned that I am with the Department of Public Works in the government of the Northwest Territories. I am an architect and a practitioner, not a researcher. For the better part of a decade, I have been responsible for the department's capital construction program. That involves between 80 and 100 million dollars of construction annually. The government's total capital budgets are almost $200 million annually or about 20% of the total territorial budget. Building is very important, and now amounts to over 10,000 assets worth many billion dollars spread out over 60 communities, ranging from water works to hospitals, and from arenas to correctional centres.

Dealing with, and to a certain extent depending on the cold is a significant planning and design issue. Buildings are oriented to work with the wind and snowdrifting patterns to keep service and access lanes trafficable with minimal snow clearing. The foundations are often designed for permafrost soil conditions and incorporate a number of devices many of you are familiar with. For instance, to overcome the movements of the active layer through spring thaw and fall freeze-up, adfreeze piles anchor the building into permanently frozen ground. Or permafrost is artificially raised to natural grade through the use of ground insulation covered with granular pads. Or light weight buildings are provided with screw jacks and other devices so that they can be releveled when the ground moves. Or, the ground is ventilated to remove built-up heat that could degrade the permafrost by using active or passive cold air ducts, or liquid cooled thermosiphons.

You would think, then, that a change in the ground temperature regime would have catastrophic consequences on foundation integrity. It could, but there are a few mitigating factors:

- life expectancy of northern facilities, for a variety of reasons, is only 25-40 years, so replacement facilities are being designed within relatively short time frames. Therefore, the impact of changed ground temperatures can be reasonably predicted and included as a design parameter.
- Buildings take a real beating in this environment, so the effects of the cold are clear and easy to measure. Therefore, innovation progresses at a visible pace.
- The rate of construction is so high that the amount of infrastructure is doubling about every 12 years. Coupled with relatively rapid changes in building technology, the newer infrastructure <u>can</u> and <u>is</u> adapting to changing environmental circumstances, whether these are geophysical, atmospheric or political.

So northern buildings are already built to retain their structural integrity in a wide range of annual permafrost ground states. Increasing the range of thermal variation as a result of climate change is within the existing design approach.

Northern buildings are also required to moderate the variable outdoor climate to create and maintain a comfortable and constant indoor environment. This variation is one of the most extreme on earth, with thermal differences of 60°C across the envelope. Humidity regimes also range in absolute terms from a desert on the outside to a

swamp on the inside. You can imagine a wood column spanning the full thickness of a wall, expanding and swelling in the warm wet interior conditions while shrinking and puckering up with the cold dryness outside. This material is being literally ripped apart. And over the course of a year the differential expansion and contraction of this poor column creates incredible dynamic loads in the component. The same visualization is done for the flow and freezing of moisture across the thickness of the envelope. So northern design begins with an image of this dynamic behavior of materials in a dynamic annual climate regime, and finds ways to deal with it. The projected global climate change imposes another but slower thermal pattern of the materials and systems of built structures, but the design visualization required to accommodate its effects is already well-developed.

The more significant impacts of climate change, no doubt, will have to do with the siting of buildings and whole communities. Decreasing water levels of inland waterways and lakes will impact community water supplies. Already we are seeing that the natural flushing action in some water sources has been affected as water levels decrease. Slope erosion and landslides will make facilities against hillsides and on river banks more vulnerable. As an example, a major section of Ft. Smith slid into the Slave River in the late 60's. Coastal communities, or low-lying sections of them could be inundated by rising sea levels. Tuktoyuktuk on the Mackenzie Delta would be a prime candidate for this kind of problem. Fortunately most of these situations develop over time, and given the relatively small and light construction used in the north, most vulnerable assets could be picked up and relocated.

So like my peers in Pond Inlet, you hear me saying "so what" to the "what ifs" of global climate change. But that's not quite the message I had in mind. The act of building facilities and communities is much more than a technical solution to the dynamic forces of ground, wind, water and temperature. Buildings and communities support life styles and building them expresses life values and culture.

The act of building in the north already forces the integration of mixed objectives and mixed scenarios. The building process had made us very aware of our connection to and our dependency on the rest of the world. In modern times, nearly all materials, all labour and all energy used in the construction, operation and maintenance of buildings was imported from somewhere else. The building activity was creating an enormous trade deficit in every sector. Lots of money was spent on construction, yet northern people learned no skills, earned no wages, invested in no businesses, and developed no capacity to participate in the construction of their own future. People resented this. Building should not only satisfy functional needs, but building in the north also presents a major opportunity for the economic development of northern communities and the self-sufficiency of northern people. It became increasingly important to develop northern capability, employment and business, including the manufacture of construction material using northern resources. Much has now been done to make that happen. Recently, we have included economic impact models in the construction process. This allows paying contract premiums where the net economic northern and local development benefits exceed the costs.

The prominence of the economic development objective in building and the desire to measure and reduce the northern dependency on the larger world have created a readiness, I believe, to take advantage of the perspective available through the climate change model. Northerners are ready to visualize not only the local impact of their dependency on the world, but the impact they have on the rest of the world. The global resources required to build homes and communities for a northern resident are still disproportionate compared to the resource budgets of other world citizens. Northerners have a very large ecological footprint. In addition, very little of the materials, labour and energy consumed in northern building get recycled in a form usable for future generations. Northern construction has a high metabolism and is far from sustainable. It becomes apparent then that northern construction, although it is very adaptable to climate change, is also a major consumer of the very industrial processes that are creating climate change. So philosophically, the technology of construction should change, even though in absolute terms, the demographics of the north are so insignificant, that changing northern building technology to mitigate global warming would have little real impact.

But I started by saying that building was an expression of life style and life values. The creation of sustainable construction that mitigates its impact on the planet's resources and also mitigates its impact on global warming would be fully consistent with the traditional knowledge of the recent aboriginal past. The north has the natural laboratory conditions and the cultural context that could support research and experimentation in sustainable building technologies and, that could provide building prototypes that help mitigate climate change. The northern settlement is an easily calibrated barometer of global impacts, and could be a visible demonstration of a more re-

sponsible attitude toward the planet.

Building is an essential act in the present to create place. The creation of place necessarily integrates possibilities and biases the present to become the future we want to live in. Dr. Cohen asked what impact the Mackenzie Basin Impact Study has on policy making for decision makers. For us, little new work has been done in adapting proactively to possible climate change scenarios. On the other hand, one element of our current business plan is the development of a methodology to measure building metabolism and sustainability, and to target reductions in the resource budgets required to build, operate and maintain them. This work then, potentially mitigates the sources of climate change, and allows us to act now to change the future.

From Round Table #3:

The Mackenzie Basin Impact Study on Climate Warming - A British Columbia Ministry of Forests Perspective

Chris Fletcher, BC Ministry of Forests, Victoria

Summary of opening comments:

I'll begin by providing some context by outlining my areas of relative knowledge and ignorance.

I am involved in forest management decision making — specifically allowable annual timber harvest determination for publicly administered forests in British Columbia. In general then, my perspective is that of a fairly high-level decision support worker who attempts to incorporate concerns brought forward by operational and policy staff. Prior to attending the MBIS final workshop, I knew very little about climate change and its potential effects on forests. Some might therefore question if I was the right person to attend the workshop and address climate change issues. However, I believe that impressions from a relative outsider may be useful both in gauging the potential effectiveness of the MBIS research in influencing public policy and resource management, and in thinking about how work may be extended to increase its utility. Nevertheless, given my ignorance about climate change in general and about ongoing initiatives in B.C., I am not a spokesperson for the B.C. government as a whole. Finally, one of my interests is decision making under uncertainty—an area very relevant to my work and, I believe, to decisions related to climate change. I was interested in seeing how MBIS researchers had dealt with the uncertainties about the rate, magnitude, spatial distribution and type of change when discussing management implications.

[I did not discuss the following climate change-related initiatives at the workshop.

The B.C. Greenhouse Gas Action Plan (B.C. MEMPR and MELP, 1995) contains over fifty proposals for policy, planning, research, education and industrial processes in the fields of energy, transportation, forestry, agriculture, solid waste management and science. Initiatives related to air quality, such as requirements and targets for more fuel efficient vehicles, and cleaner and alternative fuels (B.C. MELP no date and 1995), while not directly related to climate change, will lead to reduced greenhouse gas emissions. The proposed roles of forestry in the Greenhouse Gas Action Plan are mostly in the storage of carbon and ensuring that forests do not contribute carbon to the atmosphere, but rather reach a carbon balance over the long term. There is also an initiative to phase out remaining "beehive" burners to reduce carbon additions to the atmosphere.

There are no major climate change-related initiatives within the B.C. Ministry of Forests at this time, although the ministry contributes to discussions with the government agencies— primarily the Ministries of Environment, Lands, and Parks and Energy, Mines, and Petroleum Resources—most involved in developing greenhouse gas initiatives. Some ongoing research in the Ministry of Forests relevant to climate change includes: describing the climates of seed sources (rather than simply geographic location), so that should (when?) climate change occur, suitable seed sources can be located; and investigating the impacts of changing water regimes on tree regeneration and growth with a view to finding drought resistant species and genetic varieties.]

Why I do not think climate change in general and the MBIS results specifically will have a significant impact on forest management in the short term:

For the last four years during which I have been involved in strategic timber supply analysis and harvest level decision making, I cannot recall once being told by Ministry of Forests operational staff that potential climate change was a concern, and that we should attempt somehow to incorporate it into our analyses. I believe, therefore, that the issue is not a large concern for most people managing *forests* and developing *forest policy* in B.C. today. (My comments apply to forestry specifically. There is some significant ongoing work in greenhouse gas reduction and air quality.) I doubt many people would say that climate change is unimportant. However, many other controversial issues

with immediate ramifications fill the forestry and land use agenda. Some issues and initiatives that currently affect B.C. forestry include: implementation and monitoring of a new Forest Practices Code; land and resource management planning, in part to help clarify and resolve land use conflicts; a Protected Areas Strategy with a goal to establish more parks and other protected areas; treaty negotiations with First Nations; and a Timber Supply Review that is suggesting that over the next several decades, timber supply will most likely decline in many areas, with consequent implications for community welfare, employment, and government revenue. Debates about land use and management are highly emotional, largely I think, because the outcomes will affect people's lives in the relatively short term.

In addition, there are some substantial uncertainties about biological processes in forests (even without climate change) including: future tree growth and timber yield, succession (change in species composition over time), wildlife dynamics and habitat needs, and natural disturbance regimes and their effects on timber supply, to name some of the larger ones.

The challenge for those wishing to get climate change onto an already overloaded agenda is to show why it (rather than other issues and uncertainties) requires action *now* and, I would add, what kinds of action are needed.

The latter point leads to one of my major concerns and interests, which is getting people to account more explicitly for uncertainty when making decisions. To some extent we already do this by making decisions relatively frequently so that new information can be taken into account. However, in general, my experience is that as a society we seek to eradicate certainty rather that recognizing its ubiquity, and developing decision making tools that account for it in some way. While not disputing that climate is changing or that ecological and human social systems would be affected by this change, my summary from discussions at the MBIS workshop is that the pace, type, and magnitude of the change are uncertain. An important question therefore is: do the uncertainties about climate change and the associated risks take us outside of the range of already existing socioeconomic, cultural and biological uncertainty? Do we need to do something specific to deal with climate change, or will any actions that we can implement that deal with uncertainty in general probably cover those associated with climate change?

The challenge here for climate change researchers, I think, is to supplement illustrations of the potential impacts of climate change with suggestions for action. The practical issue, I think, is that problems with proposed solutions are more likely to get attention than those without.

Some general actions that could be useful in addressing climate are: "no regrets" management options that would have satisfactory results regardless of whether, and what type of, climate change occurs; frequent decision making to ensure incorporation of up to date information; and design of flexible institutional arrangements and legislation that will facilitate responses to change.

My final comments are related to modelling. My experience is that most people look to models for answers. To get the best answers, we therefore attempt to build comprehensive, "realistic" and consequently complex computer models. The problem with such models, from my view, is that decision makers and other stakeholders do not usually understand them. Also, they are not constructed to facilitate increased understanding of the main driving forces in a system, the sensitivity of objectives to uncertainties, and the utility of different management options to achieving objectives given an uncertain future.

The challenge is to build models (or in general, decision aids) that are understandable to stakeholders, and that increase our understanding of objectives, sensitivities and methods for achieving a balance between "optimal" outcomes and flexibility to deal with risk and uncertainty.

I also believe that prior to designing research programs and collecting a lot of information, it is useful to be clear on objectives. This usually involves explicitly building a conceptual model of the problem. If a clear conceptual model is not there, the actions taken may not achieve desired objectives. For example, a research program designed to clarify climate change impacts would likely look very different from one designed to develop collaborative networks among researchers and resource managers. While this may seem obvious, my experience is that clear statements of objectives and clear conceptual models are uncommon.

Audience questions:

1. Jim Bruce's question on the existence of data clearly showing increased atmospheric carbon and whether the forestry community is concerned that the boreal forest is shifting from a carbon sink to carbon source.

I don't think the issue is around acceptance of the information. To me the questions are, first, do climate change impacts need to be addressed now; and second, what should forest managers do about the information? The first question is relevant because of the multitude of controversial

issues on the forestry agenda at present. I've discussed the need to place climate change in this context in my opening comments. The second question is the challenge to interpret the information. Should forest managers lobby government to use all efforts to stall climate change? Should they plant different kinds of trees? Should they drastically reduce timber harvest levels (what about the political ramifications)? I do not mean to belittle the issue, but it needs to be put in context, and feasible options developed.

2. (I didn't respond to this at the time but ...) Someone (from Carleton University) asked why decision makers treat the uncertainty associated with climate change differently than uncertainties associated with other issues (essentially, why do we use uncertainty as an excuse not to make decisions about climate change and not about other issues?).

I recognize that treatments of uncertainty and risk are inconsistent. I believe this stems from a lack of explicit treatment of uncertainties when making decisions, and when preparing information to support them. However, as I have suggested above, if *particular* actions are necessary to mitigate or adapt to climate change (rather than to address uncertainty generally), the challenge is to show what is different about climate change and associated uncertainties from other issues about which there is uncertainty. Put another way, I think it's more important to get decision makers to recognize and incorporate uncertainty (perhaps using climate change as an example of the need to do so) rather than to treat climate change as a special case. At least I think that is the best way of increasing the chances that some appropriate actions would be taken.

Closing remarks/recommendations

1) In the face of uncertainty about climate change (and other issues) develop management, institutional, and legislative options that will minimize negative outcomes regardless of future conditions ("no regrets" options), allow timely incorporation of new information, and provide flexibility to enable adaptive response to change.

2) Before embarking on process design and particularly on construction of complex models, develop clear objectives and build conceptual models of the problem to increase the chance that the desired outcome will be achieved. Unfortunately, I was not specific at the workshop about my concern here. Basically, my opinion is that the general conceptual model that our (western) culture follows is that solutions will become apparent when we have gathered sufficient information. A further difficulty is that many people underestimate the gulf between researchers and management decision makers (to say nothing of that between western culture and others). To simplify, people in these two groups gather information of different types, partly because the conceptual models they follow—including measures of success, and who is involved in discussions regarding research or management decisions—are different. The general model that information collection will solve problems, combined with different languages and constituencies means the two groups don't communicate that well (this is also an issue for those involved in different types of decisions within an organization, for example between operational and strategic planning staff). Truly integrative work will, I believe, require first that we recognize that we have constructed subcultures with associated languages around different disciplines, and second that we spend time learning each others' languages. I think it's time we stopped displacing responsibility ("managers never tell researchers what they need"; "researchers do not produce usable results"). We face complex, global, and therefore, cross-disciplinary and cross-cultural, problems. If we are going to address them, I certainly think it behooves us to do what is needed (that is, communicate) to ensure appropriate work is done.

3) Following from the above, anyone wishing to affect public decisions would do well to develop some understanding of the policy and decision making frameworks into which the information will flow, and have some sensitivity to the time limitations and complex social environments with which mangers work. This will clarify the windows of opportunity in time (for example, enable participation in a planning process). It may not be enough simply to bring an issue to the table. Insight on how that issue meshes with other pertinent issues, and what types of management options are available would increase chances that the issue is addressed.

For their part, managers could champion more work on true decision support frameworks, for example, risk assessment and decision analysis, to facilitate interpretation of information, and communicate to researchers the nature of the policy and decision environment.

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From Round Table #4:

Responses to Panel Questions

Alan J. Hanna, M.A.Sc., P.Eng, Permafrost Engineering Specialist, AGRA Earth & Environmental Limited, Calgary

Question 1 - Given the climate change impacts scenario described by MBIS and related projects, what is your view of the regions future, assuming the region does not respond proactively to climate change?

General Observations on Climate Change

It is noted in IPCC 1990 that in fact some of the greenhouse gases were present in greater concentrations as much as 130,000 years ago. It is a fact that the current warming trend started in the order of 10,000 years ago at the end of the last ice age. Therefore what is happening today is somewhat less significant in the context of geological time. When considering a further movement northwards of the southern limit of permafrost under the present climate warming scenario, one should remember that the southern limit of permafrost at one time extended well below the 49th parallel.

On recent projects in western Siberia we have learned of a very large region where there have been extreme cycles in climatic conditions. This is evidenced by zones where as much as 1000 m of the permafrost thawed many years ago and has subsequently been refreezing from the surface such that today, a typical sequence consists of about 50 m of permafrost underlain by approximately 50 m of unfrozen ground, which in turn is underlain by several hundred metres of permafrost again. Therefore we can see that in all circumpolar regions the permafrost boundaries have moved quite dramatically over the years. However, there are some more recent developments in the North American Arctic that can not be ignored, such as the influence of El Niño and the fairly significant number of forest fires in the Mackenzie Valley area. Certainly what seems to be happening today is relatively faster than in the last few hundred years, however, it is still in fact very gradual with respect to most projected impacts.

The prediction of wetter summers will actually result in a positive impact as this would imply more cloud cover and greater moisture evaporation.. In addition, as the active layer will be wetter in the fall, the frozen thermal conductivity will be increased, permitting a greater cooling of the ground during the winter months. On the other hand, projections of more snow would tend to counteract the higher frozen conductivity. However, the snow projections do not seem to be strongly established yet, and in fact recent trends in the Mackenzie valley have indicated significantly less snow in the last 50 years. Thus, it seems that the wetter summers and the reduced insulating effect of lesser snow cover could, at least in the near future, actually have a positive impact on the mean ground temperature.

In spite of the foregoing comments, which tend to downplay the impact of the climate warming scenarios, it is a fact that the permafrost engineering community has been considering the potential for climate warming for at least five years. Many significant facilities have been designed with some warming consideration. It is not uncommon, for example, to assume a 1° C warming in the life of a facility - typically 20 to 30 years.

General Impact on Permafrost

Under the warming scenarios, it is expected that there will be a gradual warming of the ground surface which will generally lead to an increase in the thickness of the active layer. In many situations this will result in some thaw settlement depending on the amount of ice in the thawing zones. The most typical manifestations of the extra thaw will be more drunken forests, changes in local drainage patterns and the development of thermokarst features in areas that had previously been relatively stable. However, it is not expected that many new or unexpected impacts or processes will occur; rather it will be more of the same, simply in different locations and possibly to a slightly greater degree.

A more significant impact may occur on some facilities which are founded directly on or within the permafrost, however it should be noted that not all facilities in the permafrost regions are founded on potentially unstable permafrost. Many buildings are founded on rock, in

particular in the eastern Arctic but also in several communities in the western Arctic where competent shale, sandstone or limestone bedrock is encountered within the depth range of pile foundations. There are also many facilities which have either shallow or deep foundations founded in ice-poor terrain such that there would be no particularly adverse impact from ground warming or even thawing. many other facilities are specifically designed as 'on-grade' facilities, for example, fire halls and maintenance garages which have their own very specific thermal design, which requires that all of the heat from the facility be intercepted and some gradual warming of the ground would have minimal impact during the life of the facility.

The real impact would be on buildings with shallow foundations of ice-rich permafrost. Thaw settlement will occur, however it will be the differential settlement, which is always less that the total settlement, that will have the most severe impact. Buildings supported on piles in ice-rich permafrost could also experience some distress as the ground warms due to the resulting increased "creep" deformations in the warmer permafrost. However, the impact of surface warming on pile foundations will be delayed as it will take several years before the warming penetrates the depth zone where the majority of the load is being supported.

It is presently well within the capabilities of the permafrost engineering profession to design foundations for the complete range of permafrost conditions from Ft. McMurray in the south to as far north as Alert. All designs are based on the expected long term ground temperatures over the life of the facility - and it matters little what is causing the change in temperature.

Flow Slides

Flow slides are a very common natural phenomenon in permafrost regions and have been for a long time. In one of the MBIS posters, Aylsworth et al, have shown a clear correlation to slide occurrences and the distribution of fine-grained sediments which typically contain significant excess ice. With climate warming, there will likely be a greater frequency of flow slides both due to gradual deepening of the active layer and the projected increased frequency of forest fires. It is noted however in Aylsworth et al, that the most common occurrence of flow slides in the Mackenzie Basin permafrost region are on the less developed west side of the Mackenzie Valley. In this case the major influence will be the disruption of stream flows within the valley and the increased potential for siltation in the drainage systems.

Based on experience on the Yamal Peninsula in western Siberia, slopes as shallow as 3 degrees have experienced flow slides in the last few years. These are likely related to some seasonal extreme temperature conditions. It should be noted that in many areas of the Mackenzie Basin permafrost region, the active layer will have already experienced conditions close to the equivalent of the "2 x CO_2" scenario. The occurrence of a mild winter, with less than normal snow cover, followed by a warmer and drier than normal summer would have the effect of increasing the mean annual ground surface temperature for that yearly cycle by 3 to 4 degrees. It is likely of course that the frequency and the degree of these extreme conditions will become greater under the scenarios considered.

Another situation that will have created much more extreme conditions than the scenarios being considered is the impact of forest fires. One of the most immediate impacts is an increased frequency of flow slides occurring in burn areas. A recent flow slide adjacent to the Norman Wells Pipeline has been studied in detail and it has been recommended to Interprovincial Pipe Line by AGRA Earth & Environmental that it is not necessary to undertake any significant mitigative measures at this time.

Pipelines

It should be noted that there are many different pipeline operating conditions that would be considered for pipelines in the permafrost regions In the "continuous" permafrost region for example, a gas pipeline would be operated in a chilled mode such that no ground thawing would occur around the pipe.

In the "discontinuous" permafrost region, a gas pipeline would most likely be operated in a warm or hot condition. In a similar manner many oil pipelines would have to be operated in a warm or hot condition due to the hydraulic properties of the oil. In these cases of warm or hot pipelines in permafrost, the pipe temperatures will completely govern the conditions surrounding the pipe and therefore climate warming would have little additional impact. However, on permafrost slopes the warm or hot pipeline would likely have to be elevated or significantly insulated so as to minimize the heart penetration from the pipe into the ground; then the impact of climate warming could be more significant.

In the case of the Norman Wells Pipeline, the oil is sufficiently light that is can be pumped at relatively low temperatures. For this relatively small 300 mm diameter pipe, it is the temperature of the ground that primarily dictates the temperature of the oil in the pipeline. (This

would not be the case for a much larger diameter pipeline where the volume of the throughput would tend to govern the pipeline operating temperature.) The impact of climate warming from projects such as the Norman Wells Pipeline is expected to be very gradual and the vast majority of the pipeline will be able to tolerate such change. The more likely significant impact may be on the thawing slopes however, many of these slopes are undergoing continuous monitoring of ground temperatures and water pressures and therefore any significant impact will be noted at an early stage.

Dams and Tailings Dykes

The warming of dams will create a potential for deformation of both the dam and the foundation as warming and thawing occurs. This may require the retrofitting of some form of insulation and/or thermal modification over the years to come, however this will not require any new or particularly challenging technology. A common form of dam or dyke design in the Arctic is that of a "frozen core". Traditionally these have only been really feasible in the continuous permafrost regions and therefore the region where these will be feasible in the future will move northwards. Again, the design for facilities such as this is always based on the long-term expected geothermal conditions and it is little additional challenge to incorporate whatever warming scenario is considered appropriate for the life of the facility and risks involved.

Transportation Facilities

The majority of the highway system in the Mackenzie Basin permafrost region is within the discontinuous permafrost zone. As such the design of the roads has anticipated ongoing unstable conditions as thawing and settlement would occur underneath the road embankment. In contrast, the more northerly sections of the Dempster Highway will experience a much more gradual impact as long-term ground warming occurs. Obviously unpaved roads will be more tolerant to gradual differential settlement as the surface can be regraded more readily. Clearly there will be more significant cost factor over the long-term with paved roads. Airstrips will be susceptible to the same sort of impacts.

It is unlikely that there will be any significant design change called for as some of the mitigative measures would be quite expensive in terms of either insulation or extra fill material.

Question 2 - What responses to this impacts scenario should be considered in the region?

Some of the older facilities, especially those in the southern permafrost regions, those on shallow foundations, as well as piles in ice-rich ground could well experience some distress with time if the facilities are not retired in the near future. However, much of this potential distress can be mitigated by the retrofitting of insulation, if and when it seems necessary on a case by case basis. With respect to the future, it is well within the normal practice of permafrost engineering to consider the ground temperature conditions beneath facility over the life of the facility and if it is necessary to consider maybe a greater amount of warming during the life of the facility, that presents no particular challenge to the permafrost engineering designer.

The main response will require that owners, resource developers, and designers are made fully aware of the climate warming scenarios being considered and their potential impacts. These impacts will have to be examined with respect to the proposed lifespan of the facility or the development. In most cases this lifespan will be considerably less than the period for the scenarios, which extends in most cases to the year 2050.

It will be necessary to consider the extent to which policies and/or codes of practice for permafrost engineering should be more formally modified relative to current practice. As a general rule within the permafrost engineering profession, developments such as this are considered in technical workshops or through the publishing of papers in reviewed technical journals. However, there may be a requirement to modify for example, the relevant sections of the National Building Code or to prepare specific guidelines for permafrost engineering practice under climate warming scenarios.

Owners and designers must be prepared to make allowances for budgeting additional maintenance of existing facilities in the long term, which may include the retrofitting of some insulation or other heat interception techniques. It should also be understood that new facilities will require more conservative and therefore more costly designs at this stage.

As a final recommendation there is a considerable requirement for monitoring of actual climate change, monitoring of actual impact of ground temperatures an terrain conditions and, monitoring of the impact on facilities and developments. It will be desirable for some form of a centralized database system, established to compile all of this monitoring data, so that it can all be made readily avail-

able to all scientists and professional engineers within the impacted areas.

From Round Table #1:

Sustainability of Ecosystems

George Low, Fisheries Management Biologist, Dept of Fisheries and Oceans - Canada, Hay River, NWT

Question: Does the impact scenario make a difference to your view of the future?

Yes. If global warming occurs management strategies for fisheries will have to react to the changes.

There is no doubt that Human activity on the planet is changing natural ecosystems at an alarming rate. We hear through the media that industrial and agricultural activity is changing the face of the Earth. Whether or not global warming is one of the impacts of the industrial revolution is still being debated, however there is a high probability that we are already affecting climate.

As global warming occurs it will have an effect on the freshwater and anadromous fish stocks of the Mackenzie Basin. Climate change will affect the thermal and physical condition of lakes and rivers, directly affecting fish habitat and the varied species of fish which rely on the predictable seasonal conditions which contribute to the ecosystem. The severity of the effects will depend upon the degree of change in temperature and weather patterns and on the time frame involved.

Northern and Arctic fish have evolved to their present state through adjusting to climate change in glacial and post glacial periods associated with major ice ages. They have had thousands of years to evolve and adjust to these changes. Global warming may well force changes within a century or even decades.

Fish are very sensitive to temperature. Their body temperature and physiological processes are directly affected by water temperature since they are cold blooded animals. They are dependant on suitable thermal habitat for their survival. The entire food web on which they depend is affected by changes in climate and water temperature.

Different species of fish require different thermal habitats. In the Mackenzie Basin fish can be categorized as Cool water, Cold water and Arctic Fish.

Cool water fish have southern distributions which penetrate into the Mackenzie Basin; they include Northern pike and walleye. These cool water fish are more likely to benefit from warmer conditions further north.

- Can we expect positive effects of global warming?
- Can we expect increased abundance and growth rates for these species?
- Would fisheries benefit from increased production of these species?
- Would the distribution of these species spread northward?

Cold water species are widely distributed in the basin. They require a cold water niche to survive; they include Lake whitefish, Lake trout and Lake cisco.

- Would Lake whitefish populations in large lakes which provide cold waters at depth benefit in warmer conditions? Would growth and abundance increase?
- But would river conditions remain suitable for river spawners?
- Would Lake trout stocks continue to thrive in the deep waters of Great Slave and Great Bear lakes but decline or become absent from shallower inland lakes speckled across the Mackenzie Lowlands and the Canadian Shield?

Arctic fish are distributed at high latitude and penetrate southward into the Mackenzie basin; they include Grayling, Inconnu, Broad whitefish, Arctic cisco and Arctic charr.

- Would species such as Arctic grayling be able to survive warmer conditions? Warm water disease problems have already occurred.
- Would warming and low water conditions be the last straw for Great Slave Lake inconnu stocks which are heavily exploited by fisheries in the region?
- Would Mackenzie delta inconnu and Broad whitefish stocks continue to spawn successful in upstream reaches of the Mackenzie River?

There are so many factors involved in ecosystem changes that it is hard to predict specific consequences of climate change. Nor are there many ways to mitigate the effects of these changes. Management of the fisheries would have to be reactive.

Winter kills

Global warming may increase episodes of winter kill. Winter kill occurs in the NWT., but not frequently. Most waters are oligotrophic or not overly productive. Algae blooms, which can rob a lake of its oxygen when this or-

ganic material decays, are not common. Some shallow lakes contain no fish and winter conditions are probably a major factor in their absence. It is possible some borderline lakes could be added to this list if conditions change.

Summer kills - Disease

We have already experienced warm water related disease problems on the Mackenzie River due to some extreme summer temperatures. In August of 1989, thousands of fish including Long-nose sucker and Arctic grayling were killed in Beaver Lake and areas downstream. The kill was attributed to high water temperatures and disease caused by two opportunistic waterborne pathogens, *Aeromonas hydrophila and Pseudonionos putrifaciens.*

The outflow of Great Slave Lake because of its shallow nature skims the warmer water off the surface of the lake. This water is further warmed as it flows through shallow Beaver Lake, the Providence Rapids and Mills Lake downstream. So although the source of the Mackenzie River is a large cold lake, under certain warm and calm conditions it can supply warmer than expected water to the downstream environment.

The 1989 event had a direct affect on the management of fisheries in the region. Catch and possession limits for Arctic grayling were reduced from 3 daily and 5 in possession to zero possession during the spawning run (April 1 to May 31) on the Kakisa River, Beaver Lake and northward to the Mills Lake area. Summer catches were restricted to one daily and one in possession for the sport fishery.

Is it possible a fish stock and fishery have already experienced a negative effect of global warming? If more of these events occur, we can expect similar reductions in other fisheries.

Global warming could also affect spawning success for many reasons. Precipitation patterns could cause increased siltation, fluctuating water levels, the destruction of spawning habitat and mortality of over-wintering eggs.

Question: What should the response be to this scenario in the region?

1. The primary response should be directed towards preventing global warming or the severity of global warming by reducing the output of greenhouse gasses into the atmosphere. Since we are a small part of the global community we should also lobby for less polluting industry in the rest of Canada, North America and the world.
2. The second response should be to continue to study and monitor the phenomenon.
3. Thirdly, if global warming occurs, fisheries managers will have to change fishery management strategies in reaction to changes in fish stocks and habitat. This could include changes in quotas, allocation and location of fisheries reacting to positive or negative effects of climate change. Some management changes would be gradual; others would be sudden in response to catastrophic events such as the 1989 Mackenzie River fish kill.
4. If the additional pressure of global warming is placed on fish resources it will become even more important to manage fisheries on a sustainable basis and to protect habitat from local degradation. Contamination of waters by substances deleterious to fish would be a double whammy we should prevent at all costs.

From Round Table #6:

Recommendations

David G. Malcolm, Aurora Research Institute, Aurora College

1. Introduction

During this workshop I have become a believer in climate change. My own experience of growing up in the parklands of Saskatchewan during the 1940's when the dust drifted to the top of the fenceposts and the temperature rose to anywhere from 38°C to 44°C for days at a time during the summer, followed by what we called the "wet years" from about 1951 to 1953, when the fields were often too wet to sow, and those that were sown were often too wet to harvest, and the snow was incredibly deep during the winter, effectively hampered my belief in global warming.

However, I am now more open-minded, beginning with Walter Skinner's introductory address on Sunday on *Climate Trends.* The data he presented effectively show the Mackenzie Basin to be a global "hotspot" in terms of average temperature rise per decade, which focuses worldwide attention on the MBIS process.

2. Lessons learned from MBIS

Several lessons have stood out to me as a result of our deliberations at this final MBIS workshop. They are

listed as follows.

2.1 Effects of data variability: There is a risk of attributing trends to data which describe normal long-term climate oscillations in the region (e.g., remembering that temperatures and CO_2 concentrations were higher than normal during the 1940's).

2.2 There is a need to prepare for surprises: Regional models tend to be built around slow change (self-fulfilling prophecies), whereas nature may be full of rapid surprises as well as slow long term trends toward ice ages or widespread deserts in concert with anthropogenic interference.

2.3 There is a crucial need for ongoing, long term monitoring of the phenomena described at this workshop, with appropriate analysis and action.

2.4 Traditional Environmental Knowledge must be considered as credible and relevant.

2.5 There is a need for a risk assessment approach, linking uncertainty with causes, linkages, and scenarios.

2.6 There is a definite need for closer collaboration between affected communities and research proponents, especially in the case of Aboriginal communities, where research may highlight cultural differences.

2.7 There is a need for closer communication between and among researchers during long-term studies of the MBIS type.

2.8 In order to ensure sustainable economic development in the region, development scenarios must be careful to take social costs and benefits into account, both short and long term, as they affect the communities concerned.

2.9 The communities of the region are interested in the MBIS outcome, and high priority should be given to the preparation of plain language reports of research results for distribution to the communities.

3. How the results should be used

3.1 In the Mackenzie Basin region: The results should be communicated to Aboriginal and non-Aboriginal community leaders in plain language reports and seminars (with the assistance of existing research and cultural institutions in the region), so that the communities can begin to plan for the socio-economic impacts of climate change.

3.2 In the national arena: The MBIS results should not only be communicated to Canada's Minister of The Environment, but should be used as strong lobbying support, so that Canada's government is in a position to support communities in the region as they prepare for the impacts of climate change, i.e., as they prepare for a warmer, drier future.

4. Recommendations

Where do we go from here?

4.1 *Modelling the Way:* There is widespread apathy developing in the region, because of our small regional population and economic clout. However, we can do everything in our power to demonstrate appropriate responses, e.g., replacing fossil fuels with alternative energy forms. In this way we in the region may be the *"butterfly effect"* that brings winds of change to the halls of government in North America and around the globe, especially because the Mackenzie Basin is recognized around the world as a focal point for climate change.

4.2 *Enable Communities to React to Climate Change:* Some institutions in the NWT are already working with communities to prepare them for the consequences of climate change. For example, Aurora Research Institute (ARI) is reaching out to train community residents in the region in the area of community-based research, and ARI and Energy, Mines & Petroleum Resources of GNWT together are working with communities in the area of alternative energy project development. Communities need the tools to react to climate change.

4.3 *Continued Monitoring:* There is a need for continuing the monitoring phase of the variables of interest in the MBIS. Northern communities should be encouraged to help in this continuous monitoring phase, especially in those areas of research which correspond to the identified priorities of the individual communities.

4.4 *Risk Analysis:* Consider uncertainty and risk management as a necessary component of future integrative modelling activities.

4.5 *Future Research Priorities:* The MBIS researchers should give full support to future research in the region, such as MAGS (Mackenzie Global Energy and Water Cycle Experiment), the IASC-sponsored Bering Sea Impact Study (BESIS), which appears to be concerned with many of the same research topics as MBIS in an area which borders on the Mackenzie Basin, and the West Kitikmeot Slave Study of the Slave Geological Province to create a catalogue of base-line data in various research areas.

4.6 *Impact Studies of Coastal Region:* The MBIS did not give much attention to the coastal area at the mouth of the Mackenzie river system, or the nearer areas of the Beaufort Sea. These should be considered in future studies, such as the BESIS.

4.7 *Increase Lobbying Efforts:* There is a real need to impress upon the Minister of Environment Canada the

importance of the results of MBIS.

4.8 *Northern Scientists Conference in the NWT:* There is a real need for northern researchers to get together to discuss their common problems and challenges in the near future. The idea of such a conference has been suggested by Ron Graf of the Department of Renewable Resources, GNWT.

4.9 *Improve Communications:* Researchers involved in all aspects of the MBIS should commit themselves to ongoing communication with their network of colleagues within and outside of the Mackenzie region. In this way, MBIS can be the start of a continuing awareness of climate change and a continuing adaptation to the changes encountered.

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Appendix 4: Summary of MBIS Interim Report #1 (March 1993)

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Introduction and Objectives

The Mackenzie Basin Impact Study (MBIS) is a six-year study, supported by the Government of Canada's Green Plan and other sponsors, to assess the potential impacts of global warming on the Mackenzie Basin region and its inhabitants. Interim Report #1 describes the study framework, structure, organization, methods and data, and identifies participants.

Unique Features of MBIS

Geography: The study area is a major watershed, much of it unregulated, and contains many different ecosystems (forest, wetland, delta, etc.) and several important climate-sensitive boundaries, including tree lines and the southern extent of permafrost.

Methodology: MBIS represents one of the first attempts at integrated regional assessment of climatic change.

Science-Policy Linkages: One of the study's goals is to identify policy implications.

Partnerships: Native communities and the energy sector, along with governments, are participating in MBIS planning and research activities.

Scenarios and Uncertainties

MBIS employs scenarios of future warmer climates and changes in population and economic conditions. These are not forecasts, and there are uncertainties in the methods used and the data collected, so results must be interpreted with caution.

MBIS Interagency Working Committee Established

This committee, established in 1990, includes representatives from federal, provincial and territorial governments, native communities and the energy industry. It provides advice to the Project Leader and assists in proposal review and exchange of information. The committee has met five times and reviewed 36 proposals. Of these, 18 studies involving researchers from government, universities and the private sector are receiving at least partial support from MBIS. Work contributions from 10 other studies are being provided by government departments, universities and BC Hydro. These 28 research activities include a wide range of topics, such as permafrost, hydrology, sea ice, Boreal ecosystems, freshwater fish, wildlife, forestry, agriculture, tourism, community studies and defence.

Policy Targets Identified

Six issues have been identified. Five are related to adaptation: a) interjurisdictional water management, b) sustainability of native lifestyles, c) economic development opportunities, d) buildings, transportation and infrastructure, and e) sustainability of ecosystems. The sixth concerns limitation of greenhouse gases (carbon dioxide, methane, etc.). Given the time constraints of this study, it may not be possible to address the knowledge gaps related to limitation.

Integrated Assessment

Because of the complexities associated with studying the potential regional implications of global warming, MBIS will attempt to combine information from physical, biological and social sciences, and indigenous traditional knowledge to produce an integrated assessment. This approach attempts to include all interactions that occur between sectors, rather than focussing on them separately. Two methods are currently being developed: a) socio-economic integration using a resource accounting framework, and b) an integrated land assessment framework.

Integrated assessment will attempt to address questions related to resource management and land use, such as:

1. What are the implications of climatic change for achieving regional resource development objectives? Should governments within the Mackenzie Basin alter their current resource use policies or plans regarding water resources, resource extraction, forests, fish and other wildlife in anticipation of global warming?
2. Does climatic change increase land use conflicts among

different economic and social sectors? If potential conflicts are identified, how serious might they be and how could compromises be reached?

3. What are the possible trade-offs for alternative public responses to climatic change? Should parks and forests be managed to anticipate change or to preserve existing conditions? What are the implications for fire control, recreation, tourism and wildlife management?

4. What are the implications of global warming for community management of resources under land claims agreements?

Highlights of Results to Date

- Four scenarios of warmer climates have been developed. Three were derived from General Circulation Models (GCM). The fourth is a "composite" based on data from the past (instrumental and paleoecological records). The GCM-based scenarios for an equivalent doubling of CO_2 (assumed to be in 2050) show a warming of about 5°C, while the composite scenario warming is 3°C. All four show increased precipitation for the basin as a whole, but some decreases occur over parts of the basin during the summer.
- A population growth model has been constructed in order to produce a population scenario for the basin portion of each province and territory. Most jurisdictions would experience increases of about 0.75% per year up to the 2030s. This background information of a possible "future" allows MBIS to provide context for the assessment of climatic change scenarios.
- Four scenarios of economic growth for the basin have been developed: a) High Resource Development (3% annual growth), b) Low Resource Development (less than 0.5% annual growth), c) Low Overall Growth (decline in trade and service sectors), and d) Low Overall Growth Alternate (decline in trade, indirect reduction in service). These "futures" allow MBIS to provide context for the assessment of climatic change scenarios.
- A model of Peace River freeze-up has been developed, and is ready to be applied to scenarios of climatic warming.
- An inventory of landslides in the Mackenzie Valley has been completed. Preliminary results of thermal modelling show how thaw depth would increase in a hypothetical scenario of warmer temperatures and increased snow depth.
- A preliminary investigation on possible impacts on Beaufort Sea ice found that the open water season would increase, the extent of open water would increase accompanied by increasing wave heights, and maximum ice thickness would decrease.
- Two studies of remote communities were initiated in 1992. The first included field interviews on community responses to high water events in Fort Liard and Aklavik. Interviews were also conducted in Aklavik as part of a study on climate and land use activities.
- The community of Lutsel k'e (Snowdrift, NWT) has agreed to participate in a study on traditional knowledge of climate. Efforts are underway to seek additional funding for this work.
- A series of interviews on resource management goals was initiated. So far, these have been conducted in the upper Peace River region, Edmonton, Norman Wells, Inuvik and Tuktoyaktuk. The sample size is still too small for analysis, so additional interviews will be held in 1993.

The Next Phase of MBIS

An important component of integrated assessment is the construction of data bases that provide information on spatial patterns and economic flows within the region. During 1993-94, work will continue on the development of two data bases:

a) spatial patterns of resources, such as soils, and forest cover, and

b) central accounts of opening and closing stocks of resources, such as timber and fish.

A mid-study workshop is tentatively planned for the spring of 1994. Preliminary results from the many MBIS activities will be discussed. Workshop proceedings will be published as MBIS Interim Report #2.

Appendix 5: Summary of MBIS Interim Report #2 (November 1994)

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Introduction and Objectives

The Mackenzie Basin Impact Study (MBIS) is a six-year study supported by the Government of Canada's Green Plan and other sponsors to assess the potential impacts of global warming scenarios on the Mackenzie Basin region and its inhabitants. Interim Report #2 contains the Proceedings of the Sixth Biennial Meeting on Northern Climate & Mid-Study Workshop of the MBIS, which took place on April 10-14, 1994, in Yellowknife NWT. Rather than producing two publications (i.e. a separate proceedings for each event), the presentations and discussions were combined into this document. MBIS participants have provided progress reports and, in some cases, preliminary or final results for their activities. Papers from the Northern Climate Meeting represent a rich source of additional information that complements the research activities taking place within the MBIS programme.

Context

Assessments of global warming scenarios must account for various factors other than atmospheric change, and the importance of communicating results to decision makers and Northern communities. **Cyr (City of Yellowknife)** and **McLeod (NWT Renewable Resources)** emphasize the need to provide information that can assist planners and resource managers, and is relevant to northern residents. **Fraser (Canadian Polar Commission)** notes the lack of facilities for Arctic marine studies, and the need for a Canadian Polar Information System, which would be a comprehensive data base on past and current research. **Stenbaek (McGill University)** reviews the results of three Arctic global change workshops recently organized by the Royal Society of Canada, including one on human dimensions which expressed the need to develop new research methodologies that allow the human sciences to interact with the physical and biological sciences. **Pollard and Benton (Pacific Forestry Centre)** provide estimates on the status of protected areas in the region. This could become a very important policy issue in this region, given the potential impacts of a warmer climate on ecosystems and the current international debate on biodiversity, forests, climate change and sustainable development. **Malinauskas (Atmospheric Environment Service)** chronicles the events that led to the Earth Summit at Rio, and the signing of international conventions, including the Framework Convention on Climate Change, which has become a legally binding commitment to action on emission reductions and other measures.

MBIS Assessment Frameworks

Integrated assessment is a complex and difficult challenge, and several different approaches are being pursued within MBIS. **Cohen (Atmospheric Environment Service)** describes the development of the research program and identified the main impact-related policy questions that would be addressed (water management, sustainability of ecosystems, economic development, infrastructure, sustainability of native lifestyles). **Lonergan (University of Victoria)** outlines a methodology for resource/environmental accounting to estimate regional economic impacts of climate change. In the first of two papers, **Yin and Cohen (Atmospheric Environment Service)** describe a land assessment framework that combines information on changes in the land resource base with goals expressed by regional stakeholders, so as to identify possible land use conflicts in scenarios of climate change. **Felton (Environment Canada — Prairie and Northern Region)** reviews the current legislative and institutional setting for water management in the Basin, providing the context for assessing the management implications of scenario impacts on hydrology. MBIS is also attempting to incorporate traditional knowledge of aboriginal people into the research program. **Bielawski (Arctic Institute)** describes an effort to launch a Participatory Action Research activity on Dene knowledge of climate variability with the Dene of Lutsel k'e, NWT. So far, however, additional funding from potential co-sponsors has not been obtained.

Data and Monitoring

A considerable amount of climate and land cover information is needed for the various research activities within MBIS. The Mackenzie Basin is large, and sparsely popu-

lated, and the surface monitoring network is uneven. **Gong et al. (University of Calgary)** describe a land cover mapping exercise, using processed satellite imagery, resulting in a classification containing 13 land cover types for the Basin. This is one of the inputs needed to the land assessment framework. Additional data requirements are outlined in the second **Yin and Cohen (Atmospheric Environment Service)** paper on this framework. **Lukawesky (Environment Canada — Prairie and Northern Region)** provides information on northern weather and climate monitoring networks, including stations operated by NWT agencies and volunteers. The volunteer project being established at various NWT schools **(Burlingame, Science Institute of NWT)** may augment this network.

Precipitation and evaporation are difficult to monitor in this region. **Metcalfe et al. (Atmospheric Environment Service)** describe rainfall and snowfall measurement errors, and a method to produce a corrected precipitation archive. **Reid (Indian and Northern Affairs Canada)** compares different evaporation models for three NWT mine sites.

Climate

The Intergovernmental Panel on Climate Change has concluded that in a scenario of global warming, high latitude regions would warm at a faster rate than other latitudes. **Skinner and Maxwell (Atmospheric Environment Service)** show that Northwest Canada (including the Mackenzie Basin), Alaska and North Central Russia have warmed during this century, while the Eastern Canadian Arctic has cooled. The areas of warming have also exhibited decreases in sea ice extent and thickness. General Circulation Model (GCM) simulations project similar conditions if concentrations of greenhouse gases increase, except in the Eastern Canadian Arctic, where GCMs project a slight warming. It must be stressed, however, that the observed trends are still within the range of historic variability so it cannot yet be stated that an enhanced greenhouse effect is being observed.

GCMs do not describe local scale features, so additional studies are needed to understand how these may change. **Gibson et al. (University of Waterloo)** describe a method for estimating evaporation based on analysis of stable oxygen and hydrogen isotopes in river flow, suggesting that these could be used to improve the resolution of climatic-based evaporation maps. **Sortland (Arctic Weather Centre)** notes that storms and high winds can generate waves of up to 3 m on Great Slave Lake. This is a reminder that the Beaufort Sea is not the only place in the Mackenzie that can experience this kind of extreme event, so wind and ice information is also needed at the scale of the large lakes. At a larger scale, **Taylor (Environment Canada — Pacific and Yukon region)** explores the use of the Southern Oscillation Index as a predictor of Yukon winter temperature and precipitation.

Water

Interjurisdictional water management is a major focus of the MBIS, and several activities are underway to provide scenarios of hydrologic impacts. **Lawford (National Hydrology Research Centre)** provides background information for the Basin. There are many unknowns, including the role of wetlands, permafrost and large lakes on the overall runoff regime. If the climate changes, these features may also change, adding further complexity to the hydrologic impacts question. The Global Energy and Water Cycle Experiment (GEWEX) includes a study of the Mackenzie, and will address many of these research issues over the next several years. Given the time constraints of the MBIS, however, there is a need to provide a first cut estimate of these impacts with currently available methods.

Soulis et al. (University of Waterloo) provide estimates of changes in basin runoff for three climate change scenarios using a square grid technique developed in the 1960s. All scenarios include higher mean annual temperature and precipitation. Results for two GCM-based scenarios (Canadian Climate Centre or CCC, Geophysical Fluid Dynamics Lab or GFDL) show that overall annual runoff decreases by 3.7% and 7.1%, respectively, while an increase of 7.1% is estimated for the Composite scenario (a warm analogue derived from historic and paleoecological data). An earlier and longer snowmelt period is indicated. The higher precipitation in these scenarios appears to be more than offset (in the GCM-based scenarios) by increased evapotranspiration during the growing season.

Changes in sub-basin runoff can vary from the result for the Mackenzie Basin as a whole. There may also be differences between studies of the same watershed resulting from the application of different hydrologic models and interpolation methods. For Williston, **Soulis et al.** calculates a reduction of 1.5% in mean annual runoff for the CCC GCM-based scenario, while **Chin and Assaf (BC Hydro)** show an increase of 6% using the UBC watershed model and the same scenario. Both show an earlier, lower snowmelt peak, and both conclude that increased evapotranspiration offsets (to some degree) the 11% increase in precipitation in this scenario.

The earlier peak may affect the operation of the BC Hydro facility at Williston Lake, and ice formation on the Peace River downstream from the Bennett Dam. **Andres (Trillium Engineering)** estimates that ice progression will not reach as far upstream in a climate warming scenario, and that the ice season will be shorter by more than a month at some locations. If the outflow of the Bennett Dam is reduced, this would offset the effects of higher temperatures, and the ice regime would be similar to current conditions.

Water levels in river channels and deltas would also be affected by changes in runoff. **Aitken (Environment Canada)** and **Jasper and Kerr (Environment Canada)** describe efforts to produce routing models for the Peace-Athabasca Delta, and the Mackenzie River and Delta, respectively. These models will use the runoff scenarios as inputs in the next phase.

Land

The northern two-thirds of the Basin is underlain by permafrost. A climate warming could lead to poleward retreat of permafrost and increases in the active layer, with side effects on the landscape. Within the study area, however, permafrost is found in different settings, and impacts may be felt at different rates. In peatlands of the Southern Mackenzie Basin, **Vitt and Halsey (University of Alberta)** report that permafrost changes lag behind climatic changes, due to the insulating capacity of Sphagnum. Within the Mackenzie Valley, however, many landslides related to climatic factors have already been observed. **Aylsworth and Egginton (Geological Survey of Canada)** describe several processes that may be responsible, including changes in proximity of warm water, destruction of the insulating organic cover by fire, high precipitation events and high summer temperatures. **Dyke (Geological Survey of Canada)** provides complementary analysis for the Mackenzie Delta and its river channels. Impacts of climate warming here will vary with site since there are already considerable differences in ground temperatures between the relatively warm vegetated areas in the Delta and the adjacent upland tundra of Richards Island and Tuktoyaktuk Peninsula. Along the Beaufort Sea coast, including the Tuktoyaktuk Peninsula, erosion has already been so severe that a sandbag seawall was installed in 1987. **Solomon (Geological Survey of Canada)** shows that coastal recession of up to 100 m has occurred during the last 50 years. If climate warming leads to increased storm surges (due to reductions in sea ice and corresponding increases in open water fetch), coastal recession could accelerate.

Vegetation

Besides their influence on permafrost, peatlands and wetlands are important features of the Boreal (or taiga) ecozone. **Nicholson et al. (University of Alberta)** describe a methodology for modelling the effects of climate warming scenarios on eight peatland types found in the Mackenzie Basin. These types have distinctive characteristics, including pH, and are indicators of local climatic conditions, including height above the water line. This represents an alternative approach to assessing impacts of climate change on water levels. It will be interesting to see if the hydrologists and botanists produce similar scenarios of water level changes.

The study on forests consists of several linked research activities **(Benton, Pacific Forestry Centre)**, conducted by a team from three universities, British Columbia Ministry of Forests, and Natural Resources Canada (Pacific Forestry Centre). **Booth and Marshall (University of British Columbia)** describe a forest growth model that accounts for changes in climate, fire and insect stress. Results will be provided for white and black spruce, lodgepole pine, jack pine, trembling aspen and paper birch. **Sieben et al. (University of British Columbia and collaborators)** are investigating potential changes in the range of the white pine weevil, using a weevil hazard rating based on heat accumulations above a threshold of 7.2°C. Preliminary indications are that for a hypothetical scenario of 2.2°C warming, the weevil hazard rating would increase for most low elevation sites in BC, Alberta and Saskatchewan, and along the Mackenzie River as far north as Fort Good Hope. This is, however, only a temperature indicator. Other factors (e.g. availability of a suitable host tree, overwinter mortality, predators) have not yet been considered. Another climate-based indicator is the Fire Weather Index (FWI), and this is being applied by **Kadonaga (University of Victoria)** for scenarios of climate warming. The GFDL and CCC GCM-based scenarios produce large increases in median FWI, corresponding to increases in burned area of 40 to 81%. The Goddard Institute for Space Studies (GISS) GCM-based scenario projects a much smaller increase, and possibly a decrease.

If fire frequency and severity changes, it could affect species type and abundance. **Wein et al., (University of Alberta)** document vegetation changes that have been observed following fire at various sites in the Basin. These include successful colonization of jack pine and trembling aspen at the expense of spruce, and encroachment of weedy species in wetland areas.

Wildlife

Land and water impacts are important agents of change in a scenario of climate warming. **Latour and Maclean (NWT Renewable Resources)** describe their attempt to assess the influence of fire on furbearers, including lynx, marten and red fox. Observations taken at sites within the Fort Norman to Fort Good Hope region show wide variability in the abundance of furbearers in burn areas, so additional sites will be examined before scenarios from the forest studies are used. Similarly, **Gratto-Trevor's (Canadian Wildlife Service)** assessment of shorebirds in the Mackenzie Delta is currently focussing on acquiring field data on food availability (insects) and habitat preferences for breeding, so that scenarios can be considered in the next phase. Concerns are raised regarding possible changes in the insect life cycle, flooding, coastal erosion rates and other parameters that could affect shorebird survival. Climatic conditions for migratory geese appear to have improved during the recent warming (particularly since 1970), but future conditions depend on whether the Arctic tundra maintains itself in a scenario of continued warming **(Maarouf, Atmospheric Environment Service)**.

Freshwater fish may be affected by changes in thermal habitat caused by higher air temperatures, and by any changes in the hydrologic regime. **Reist (Fisheries and Oceans)** notes that these changes may result in impacts on fish distribution, local abundance and growth, ecosystem structure, fisheries yields, and cumulative effects when a warming is combined with other scenarios (e.g. changes in management). **Melville (Saskatchewan Research Council)** is investigating thermal habitats and yields for lake trout and whitefish in Athabasca and Great Slave Lakes. Field observations indicate that it should be possible to predict lake thermal regimes and fish yields from air temperature, though the role of windspeed has not yet been defined.

People: Communities

If land and water are agents of climate change affecting wildlife, then these same agents will also affect communities. The Mackenzie Basin includes a mixture of community types, some based on non-renewable resources (e.g. oil and gas), others on traditional native lifestyles (e.g. hunting, fishing). In the first of two papers, **Bone et al. (University of Saskatchewan)** describe a methodology for assessing the potential effects of a warmer climate on settlement patterns. In advance of acquiring information from other MBIS activities, a data base on current settlement patterns is being constructed from federal and Territorial government sources.

At a more detailed level, **Aharonian (University of Victoria)** examined perceptions of possible climate impacts in Aklavik NWT, based on interviews with 78 people from the community. He found that residents have noticed recent changes in extreme events (new high temperature records), rather than changes in mean conditions. When asked about impacts of a future warmer climate, residents provided detailed visions of the future of their community in a warmer climate under scenarios of continued subsistence (traditional) lifestyles, or shifts to greater economic development and wage employment. For instance, muddy roads and a longer ice free season would have indeterminate impacts in a subsistence scenario, but negative impacts in a wage economy scenario. Conversely, changes in wildlife habitat would have negative impacts in a subsistence scenario, but would be indeterminate in a wage economy.

Newton (John Newton Associates) also examined community level responses in Aklavik, as well as Fort Liard, NWT. His focus was on response to flooding, and included observations taken during the 1992 floods in both communities. There were differences in perception of the flood hazard, and in responses to the 1992 events. Past experience and monitoring of ice and snow conditions are seen as important influences in both communities, but responses operate at different levels: individual, community, and government. The interplay of these levels lead to unique responses by communities. His conclusion was that the relatively modest hydrologic impacts projected by **Soulis et al.** would not require significant changes in community responses, and that changes in social structure and economic conditions would be more important determinants of future vulnerabilities to flooding.

People: Economic Activities

The relationship between climate and economic activities is complex and often involves indirect linkages through various agents of change (land, streamflow, ice, vegetation, habitat, fire, etc.). Several MBIS activities focus on specific economic activities which may be sensitive to a change in climate. **Anderson et al. (McMaster University)** describe a methodology for assessing impacts on the economic viability of oil and gas production, particularly in the Mackenzie Delta/Beaufort Sea region. One of the important questions is whether a change in sea ice and permafrost can significantly alter the economics of tanker shipments and pipelines. A related study on non-renewa-

ble resources, focussing on case studies of Norman Wells (oil), Fort McMurray (oil sands), Tumbler Ridge (mining), Cluff Lake (mining) and Tuktoyaktuk (oil) is described in the second of two papers by **Bone et al. (University of Saskatchewan)**.

If there are changes in hydrology, vegetation and wildlife caused by scenarios of climate warming, there could be economic impacts. **Armstrong (University of Alberta)** provides information on a methodology for assessing potential impacts on timber supply, drawing upon results obtained from the forestry studies described earlier. **Staple and Wall (University of Waterloo)** present a case study of Nahanni National Park Reserve, and conclude that in a scenario of warmer climate, tourism impacts would be mixed. Hydrologic changes would not be large enough to affect white water rafting. A warmer climate would extend the visitor season by four weeks in the fall, providing additional economic benefits for the Nahanni region. However, projected increases in fire frequency could affect visitor safety, and subsequent changes in the landscape could alter the hydrologic regime. Another tourism study, still in progress, examines possible effects on sport hunting of the Bathurst caribou herd **(Brotton and Wall, University of Waterloo)**. Changes in the herd's life cycle will be determined for scenarios of climate warming, using a methodology originally developed by the Canadian Wildlife Service for the Porcupine herd.

A warmer climate could also increase the capability of land to support commercial agriculture in areas with suitable soils that are currently limited by short growing seasons. **Brklacich and Curran (Carleton University)** are assessing potential opportunites for expanding production of spring-seeded grains (wheat, oats, barley, etc.) and forages (hay, etc.). Preliminary indications are that there would be an increase in marginal and suitable land because of the longer and warmer frost-free period. There would also be decreases in moisture supply in the CCC GCM-based and Composite scenarios. The next phase will consider the potential for agricultural adaptation to future changes in climate.

Discussion on the Progress and Future of MBIS

The Yellowknife workshop concluded with a Round Table discussion, in which participants were asked to assess the progress of the MBIS exercise, make suggestions for improvements, and suggest what could be done to assist the North in achieving sustainable development. **Kertland (Atmospheric Environment Service)** served as rapporteur and provides a summary of the discussion. The Round Table members were **Dixon Thompson (Royal Society of Canada)**, **Terry Fenge (Canadian Arctic Resources Committee)**, and **Fred Roots (Environment Canada)**. **Barney Masuzumi (Dene Nation)** was in Fort Smith and unable to participate. Integration and communication were the main themes, and it was felt that there were shortcomings in both areas. There were concerns that the various pieces didn't fit together. The workshop itself was seen as a useful means of facilitating communication between the various participants and stakeholders, but there needs to be more direct contact with Northern communities. On the other hand, MBIS is now operating in a different social, political and financial environment than that which existed in 1990, and expectations have risen. Political changes in the North could lead to new opportunities for consultation with recently created community-based resource management boards.

In "The Second Half of MBIS," **Cohen (Atmospheric Environment Service)** responds to the above concerns by providing information on new activities that have been initiated during the intervening 6 months between the Yellowknife workshop and the publication of this report. Two more projects have been added to strengthen the integration effort: 1) Multiobjective Program Modelling **(Huang, Atmospheric Environment Service)**, and 2) Two Economies: The Implications of Climate Change for Aboriginal Peoples of the Mackenzie River Basin **(Lonergan and Kavanagh, University of Victoria)**. The latter has been made possible by a grant from the Government of Canada's Environmental Innovation Program. There will also be a workshop on water management issues in 1995. Regarding communication, a regional speaking tour is being arranged for March 1995, with the assistance of the Science Institute of the NWT and other agencies in Yellowknife. The final workshop for MBIS will likely be held in 1996, to be followed by another regional speaking tour.

Appendix 6: MBIS Documents, 1990–1997

Editor's note: The following lists refereed papers, contract reports, MBIS reports and newsletters, presentations at conferences and student theses.

Anderson, W.P. and M. Kliman, 1993. *The Effects of Climate Change on the Energy Sector of the Mackenzie Basin.* McMaster Institute for Energy Studies, Progress Report 1. McMaster University, Hamilton, Ontario.

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Bone, R.M., 1996. *Final Report: Non-renewable Resource Study.* A Report for the Mackenzie Basin Impact Study, Environment Canada. Signe Research Associates Ltd, Saskatoon, Saskatchewan.

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Brotton, J. and G. Wall, n.d. *The Implications of Cimate Change for Selected Sport Hunting Facilities in the Northwest Territories.* A Report for the Mackenzie Basin Impact Study, Environment Canada. Department of Geography, University of Waterloo, Waterloo, Ontario.

Brotton, J., 1995. *Climate Change and the Bathurst Caribou Herd in the Northwest Territories.* MA Thesis, Department of Geography, University of Waterloo, Waterloo, Ontario.

Brotton, J. and G. Wall, 1997. Climate Change, and the Bathurst Caribou Herd in the Northwest Territories, Canada. *Climatic Change,* 35, 1, 35-52.

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